STATE OF NEW YORK

DEPARTMENT OF TRANSPORTATION

REGION 4 ROCHESTER, N.Y.

HUGH L. CAREY, Governor • RAYMOND T. SCHULER, Commissioner • A. J. KOPCZYNSKI, Regional Director

A BRIEF REPORT ON

"ALKALI - AGGREGATE REACTIONS IN NEW YORK STATE"

by

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Introduction

Alkali-aggregate reactions have occurred in our portland cement concrete structures for many years; prehaps as long as we have been using concrete in this State. Evidence of these reactions can be found in our upstate New York structures, from Albany in the east, to Buffalo in the west. They reach catastrophic proportions in the central and western areas of the State. Fully 50% of all concrete structures in the six county Rochester New York Region of the Department of Transportation are affected to one degree or another.

This pernicious form of concrete deterioration has, in all probability, cost our employer, the hard pressed New York State Taxpayer, literally hundreds of millions of dollars over the years! It will surely cost many millions more to repair and replace debilitated units before we are able to get this reaction under control.

Over the last 15 years or so, several Department field investigations failed to detect any evidence of these reactions in any of our New York State concrete. Consequently, the Department has never looked upon these reactions as a cause for concern. All serious concrete deterioration problems associated with our field concrete, have invariably been attributed, by the Department, to the lack of a proper air void system in the distressed concrete.

Given these two diametrically opposed explanations of our concrete problems, it is clear someone is wrong! Either alkali-aggregate reactions are responsible for our severe deterioration problems,or they are not. To substantiate my evaluation of existing conditions, I shall refer to various Department research reports as well as some pertinent correspondence. As you would expect, I shall be rather critical of the errors found in these reports. When we then assemble only the true facts, we will clearly see that they point logically and unerringly in the direction of alkali-aggregate reactivity in our portland cement concrete.

It would of cause, be best to discuss each and every point in minute detail leaving no stone unturned; and this I am prepared to do. Unfortunately the 3 hours allotted to me to make my presentation is insufficient for the task. So I have tried the best I could to squeeze some 16 years of my work involving the investigation of more than 1000 major structures into this relatively short period of time. I have tried to develop my report in a fashion that would make this rather complex and controversial subject understandable to any average engineer who is familiar with at least some of the rudiments of portland cement concrete. Despite its brevity, I believe the report adequately delineates all the vital points that need to be considered.

There are two parts to my report. Part I consists of numerous samples of distressed concrete that I removed from concrete units in and around the Rochester, New York area. These samples illustrate many of the points covered in this report. Numerous colored photographs of our statewide distressed concrete have also been made available for your study, as are samples of western New York aggregates associated with our distressed concrete in this area of the State. The gravel, Onondaga Limestone and Lockport Dolomite aggregate samples were taken from producer stockpiles.

Part II of the report, consists of an 80 or so page report that will be given in conjunction with the showing of some 300 illustrative slides.

Quite obviously I can never present all of the included information in the 3 hours allotted me. Therefore, I shall have to skip over several portions of the report and proceed rapidly through other sections in order to finish on time. Hopefully this procedure will not prove to be too distracting. Since you have all been given a copy of the general report, you may refer to the affected passages as you desire and at your convenience. Because of the previous stated reason, I would ask you to withhold all questions until I have completed my presentation.

Before beginning this presentation, I would like to say that I am pleased to have Mrs. Katherine Mather here today. I only wish that I could have met with her 16 years ago! So that Mrs. Mather will not labor under any misconceptions, I should state that I am not a professional engineer, chemist or geologist. I am primarily a field construction engineer with a self taught knowledge of construction materials.

Section 1

(1)

This first group of slides serves to illustrate the vital role played in our transportation system by the 16,000 bridges and thousands of miles of roads here in New York State. The original criteria used to justify the design and construction of this intricate highway system, was based on establishing a low cost, safe and efficient travel way for the use of the travelling public, as well as our intrastate and interstate bussinesses. It was these considerations that prompted millions of New York State Taxpayers to make their multi-billion dollar investment in our transportation system. (2)

When the system breaksdown, the safety of the travelling public may be threatened, businesses suffer and may even fail, and the return on the investment drops precipitously. To get the system functioning properly again, more of the taxpayer's money must be pumped into the system. All other things being equal, the greatest rate of return is derived from those systems requiring the least amount of maintenance.

Portland cement concrete is specified, designed, produced, sold and purchased on the basis that it will need little future maintenance. For this reason it is used extensively in our buildings, bridges and dams. (3) To the man on the street as well as many of our engineers, the word concrete means durability.

(4)

Vital structures, such as this bridge over Irondequoit Bay near Rochester, New York, are expensive and take several years to build. This one cost approximately 11 million dollars. It was

started in 1966 and completed in 1969. If it were being built today it would probably cost twice as much.

Section 2

It is gratifying to find that many of our old concrete bridges and roads do function with a minimum of problems just as they were designed to do, while our newer units, less than ¼ their age, fail rapidly. Is it possible that our concrete technology has been regressing rather than progressing over the years?

Section 3

Why then, do we have failures such as these in our concrete structures, and why is the problem so acute in the western and central New York area? Surely our state engineers in these two sections of the state are as capable on the whole as those in any other section of the state! If the problem does not lie in the actual construction procedures then we will have to seek the answer in our material specification requirements.

Let us now take a look at some other problems we find in our field concrete.

One reoccurring deterioration problem is the scaling of concrete surfaces. Scaling is the term that is used to describe the physical breakdown of the mortar fraction of the concrete.

It occurs when the porous cement paste becomes saturated and breaksdown under repeated freeze-thaw stresses. If less than ¼" of surface material is lost, it is called light scaling. If more than 1" of surface material is lost, it is called heavy scaling. Heavy scaling invariably involves the loss of at least some of the large coarse aggregate particles. It follows then, that the stronger and more impervious the mortar fraction is, the less likely the exposed surface is to scale.

Hence good concrete mix design and construction practices attempt to promote these highly desireable features in our finished concrete products.

To further enhance the quality of the mortar fraction, billions of minute air bubbles are purposely entrained in it. They serve as reservoirs that dissipate the destructive freeze-thaw forces at and near the exposed surfaces of the concrete. Concrete containing a proper air-void system is many times more resistant to scaling than is similar concrete without a proper air-void system. The benefits derived from air-entrainment vary from "enormous" in the weaker mixes with low cement factors, to"insignificant" in the stronger mixes with higher cement factors. Air-entrainment is no miracle worker! It does not make good concrete out of bad concrete. The exisitence of numerous old concrete pavements and structures built long before the principles of air-entrainment

were developed, still in good condition, graphically illustrate this point.

The use of road de-icing salts exacerbate our scaling problems, by increasing the number of freeze-thaw cycles occurring at or near the exposed surface of the concrete. The weaker the mortar fraction, the more severe the effects of salt attack. De-icing salts do not crack concrete! However, if the surface of the concrete is already cracked, or if the mortar fraction is porous enough to permit salt solutions to penetrate to embedded reinforcing steel, rusting of the steel will occur, promoting additional cracks in the exposed concrete surface. (Slides of no salt problems) - (39) (40) (41) (42) (43) (44) (45) (46) (47) (48)

Now I have taken the time to briefly discuss the purpose and the effect of air-entrainment in concrete mixes, as well as the effects of road de-icing salts on these same concrete mixes, in order to emphasize the point that they both deal with the surface deterioration of concrete units. For the last 15 years or so the Department has categorically attributed all N.Y.State concrete deterioration problems to road de-icing salts and the lack of proper air-void systems in the distressed concrete. Therefore, if sufficient evidence exists to indicate our concrete problems are internally generated, we can then conclude that the Department is incorrect in their evaluation, and our problems are due to other factors.

Since the fine and coarse aggregate particles constitute approximately 70% of the volume of a given yard of concrete, it is reasonable to ask if prehaps they may be the source of our concrete deterioration problems.

Where unsound fine aggregates are incorporated into concrete the concrete tends to fail in a scaling like manner. Hence, they will not normally produce deep fracturing of the concrete surface.

(49) WYO '22

Where physically unsound coarse aggregates are incorporated into relatively thin concrete members in a porous mortar matrix, the possibility exists that subsequent freeze-thaw cycles may produce detrimental expansive forces in susceptible saturated coarse aggregate particles. This action under these very special conditions may produce relatively deep seated cracking in the concrete unit. In the thousand or so concrete structures I have studied over the last fifteen years, I have never once found evidence of this type of failure!

But physically unsound coarse aggregates have been <u>even recently</u>, incorporated in our State concrete, quite inadvertently I am sure. When they fail they produce the effect we see here in this Wyoming Co. bridge built in 1922. (Failure of Slabs) (50) WYO '22 (51) → (52) In this case the mortar matrix is relatively more durable than the large coarse aggregate particles. The mode of failure is even more

(53) LIV '67

pronounced in our later concrete units as seen here in these slides of a concrete monolithic bridge deck and adjacent pavement built in Livingston Co. around 1967. Due to the air-entrained mortar fraction's far superior durability features, (54) LIV '67 the voids left by the disintegrated coarse aggregate particles are easily discernible. From what we have just seen, we can conclude that physically unsound coarse aggregates do not normally produce extensive cracking in our field concrete.

But as all engineers in the field know, it is inherent in the nature of concrete to crack, due to its limited ability to withstand tensile stresses. These stresses may develop due to loading factors, mix considerations, poor curing conditions, or even because of an imbalance of certain chemical compounds in the cement used.

In addition, other cement compounds such as the free lime (CaO), excessive Magnesia (MgO) and tri-calcium aluminates (C_3A), are fully capable of producing detrimental expansive cracking in the hardened concrete similar to those that are caused by alkali-aggregate reactions. How then is it possible to separate one from the other we may ask?

Fortunately, alkali-aggregate reactions exhibit their own unique distinguishing characteristics that permit us to determine with absolute certainty what role, if any, the reaction may have played in our cracking problems.

The advance stages of deterioration often mask alkali-aggregate related features. Hence any perfunctory examination of the distressed unit may well result in an inaccurate appraisal of the true situation. Since portland cement represents the single most important material in concrete, I began my investigations, back in 1961, by attempting to relate concrete deterioration to cements used. I compared over 300 individual pours in five different structures built in Rochester in the 1953 to 1955 time period. My evaluation of the accumulated data indicated such a relationship did exist. From that point on I concentrated on finding out why some cements promoted concrete deterioration while others did not.

To the best of my knowledge the Department has never researched our concrete deterioration problems from the aspect of the cements involved.

(55) ONT '30

It was conditions such as we see here in these slides of structures containing both good and bad concrete, that first piqued my curiousity.

ONT '30 → → ORLS '10 → ORLS '54 → → →

(56) (57) (58) (59) (60) (61) (62) (63)

Go to tray no. 2.

FACTORS AFFECTING CONCRETE DETERIORATION

	Scaling	Popouts	Warping	Excessive Cracking	Permanent Expansion	Heavy Exudations	Deposits In Concrete	Tan Stains	Rimmed Aggregates
Mix Proportions	X	X	X	X					
Water/Cement	X	X	X	X					
Aggregates	X	X	X	X	X				
Workmanship	X	X		X					
Freeze/Thaw	X	X		X					
Curing	X	X	X	X					
De-Icing Salts	X	X		X					
Air-Entrainment	X	X							
Cement	X	X	X	X	X	X	X		
Cement-Aggregate Reactions	X	X	X	X	X	X	X	X	X

Section 4

(1)

This chart is a summary of many of the ideas we have just considered. The important point here is that only chemical reactions between susceptible concrete aggregates and aggresive cement compounds, are capable of producing two very unique and distinguishing effects associated with so much of our distressed concrete in the field. The two unique characteristics involved, are the presence of rimmed fine and coarse aggregates in the distressed concrete, and the build up of an amorphous tan stain on the exposed concrete surfaces.

A third important feature of cement-aggregate reactions is the production of chemical deposits in the distressed concrete. However, these deposits are not readily distinguishable from deposits attributable to other factors. Indeed, sophisticated investigative equipment such as the electron probe are often needed to even detect their presence. As an individual with limited finances, working on his own time with only the crudest investigative type equipment available for use in my work, I have to say that I have never been able to differentiate for a certainty, between deposits attributable to so called alkal-aggregate reactions and those deposits attributable to other causes.

(2) GEN 15C '67

Here is a slide of the type of concrete distress we are considering here today. It depicts a portion of a wingwall of a Genesee Co. bridge built in 1956. The coarse aggregates are

from the cherty Onondaga Rock Formationof western New York. The slide was taken in March, 1976. Note the manner in which the concrete fractures; the heavy exudations accompanying the distress; and the distinctive tan stain on the surface of the concrete. If you break off a piece of this concrete and examine it closely, you find rimmed coarse aggregates and a considerable quantity of chalky white material. All of these features, either in part or in total, have been associated with alkali-aggregate reactions in other sections of the country as well as in Canada.

For those who are unfamilar with alkali-aggregate reactions, let me take a minute and very briefly explain how they occur in concrete.

There are basically two types of alkali-aggregate reactions; alkali-silica and alkali-carbonate. In both cases, reactive constituents in the aggregates combine with critical quantities of sodium and potassium oxides in the particular cement, If the environmental conditions are favorable the reaction will produce deleterious expansive forces within the concrete mass. When the concrete mass is no longer able to accommodate the generated forces say by creep, or some built in restraint mechanism, it begins to visibly crack. The cracking continues as long as the environmental conditions are favorable and sufficient reactive constituents are available.

In the case of alkali-silica reactions, the cement alkalies attack the siliceous constituents of the aggregate producing a silica-gel. If this gel is formed outside of the aggregate it may imbibe moisture through the process of osmosis, thereby producing large internal expansive forces within the concrete mass. If the gel is formed inside the aggregate particles, say in the pores, the aggregate may swell and produce the expansive forces in this manner.

Alkali-carbonate reactions are somewhat different in nature and vastly more complicated. The reaction involves nondolomitic carbonate rocks, highly dolomitic carbonate rocks, and impure dolomitic rocks. Present thinking has it that only the reaction involving the impure dolomitic rocks will produce harmful expansion in the host concrete. The presence of magnesium hydroxide (brucite) in the expanded concrete is strong evidence that this reaction has taken place. Reaction products are usually very difficult to identify.

The rapidity and intensity with which an alkali-aggregate reaction occurs will be affected by the following factors;

1. The alkali content of the cement.
2. The reactivity of the aggregate.
3. The pessimum ratio. That is the quantity of reactive aggregate producing the maximum expansion.
4. Aggregate size.
5. The cement content of the mix.
6. The fineness of the cement.
7. The water/cement ratio of the mix.
8. The presence of entrained-air.
9. Environmental factors including moisture availability and temperature range.
10. Wetting and drying conditions.
11. The dimensions of the unit.
12. The degree of restraint involved.
13. The creep characteristics of the concrete mass.
14. The presence of de-icing salts.
15. The passage of time.

The possibile combinations are infinite. Hence it is not surprising we find considerable variations in the physical appearance of affected concrete in the field. The best we can hope for is that they will share a few common characteristics by which the reaction can be identified. My investigations indicate that it takes between 12 and 16 years before the vast majority of these reactions are recognizable in the field. In general, the earlier the reaction appears, the more severe the final results.

In central and western New York coarse aggregates from the Manlius, Lockport Dolomite and Onondaga Limestone rock formations are used extensively in our concrete. The Manlius is a dolomitic limestone formation that contains several argillaceous members. It extends from Seneca Falls in the west, to Albany in the east. The Lockport Dolomite rock formation also contains several argillaceous members. It extends from Niagara Falls in the west to just east of Syracuse. The Pennfield member of the Lockport formation is extremely siliceous, containing as much as 52% quartz sand. The Pennfield is used extensively as a coarse aggregate in concrete in the greater Rochester, New York area. The Onondaga Limestone rock formation contains several very cherty members (up to 60%). It extends from Buffalo in the west to Albany in the east. Gravel deposits are scattered throughout the state and are also used extensively as a source for fine and coarse aggregates in concrete.

Over the years, various test procedures have been devised in

order to evaluate the potential reactivity of both siliceous and carbonate aggregates. Some of the more important ones are as follows;

1) ASTM C227 - Potential Alkali Reactivity of Cement-Aggregate Combinations.
2) ASTM C289 - Potential Reactivity of Aggregates (Chemical Method)
3) ASTM C295 - Petrographic Examination of Aggregates For Concrete.
4) ASTM C342 - Potential Volume Change of Cement-Aggregate Combinations.
5) ASTM C586 - Potential Reactivity of Carbonate Rocks For Concrete Aggregates (Rock Cylinder Method)

None of these tests have ever been adopted by the NYSDOT for the evaluation of our concrete aggregates. As useful as these tests are, they all have their shortcomings. No laboratory test has yet been devised that can duplicate the infinite combination of factors that occur in our field concrete. So in the long run, field results must always take precedence over laboratory tests.

If alkali-aggregate reactions occur in our New York State concrete, it follows that at least some of our aggregates must be chemically reactive. The natural question to ask is what information is available to indicate which aggregates are potentially reactive?

⑤

On page 10 of NRMCA Publication #149, dated March, 1975, in an article entitled "New Concern Over Alkali-Aggregate Reactions", Bryant Mather sets forth the following criteria for the early recognition of potentially reactive siliceous aggregates; ⑥

"....A fine or coarse aggregate will be evaluated as potentially reactive if petrographic examination reveals any of the following;

1. The presence of opal
2. More than 5% chert in which chalcedony is detected.
3. More than 3% glassey igneous rocks in which any acid or intermediate glass is detected....."

N.Y. State has aggregates that meet this criteria.

(7)

Some thirteen years earlier, in 1962, Dr. James Dunn and Michael Ozol completed NYSDOT PRP#12, RR 62-7. The title of the report was "Deleterious Properties of Chert". It was a study of 6 working groups of cherts found in the Onondaga Rock Formation in the central and western area of New York State. As I said earlier, the Onondaga is a major aggregate producing rock formation and extends from Buffalo in the west, to Albany in the east.

(8)

They described the silica found in the 6 working groups of cherts as being in the form of;

1. Microcrystalline quartz (M), 79-89%
2. Cryptocrystalline quartz, (K), 0-7%
3. Chalcedony (C), 0-5%
4. Megaquartz (Q), 0-5%
5. Some Opal

They could not verify the presence of opal due to the limitations of the X-ray equipment used. The balance of the cherts contained Dolomite crystals, 2-7%, and Calcite, 1-10%. The chert content of the Onondaga exceeded 60% in some of the formation members.

Considering Mather's criteria and Dunn's and Ozol's analyses of the Onondaga cherts, it not too surprising to find that at least five of the six working groups of cherts tested for potential chemical reactivity under ASTM tests C289 and a modified C227, proved to be potentially reactive. The alkali content of the

cement used in the C227 tests was determined to be 0.89%.

The findings of this report, at least to me, represented a major breakthrough. Surely I thought, the Department would now adopt the suggested control procedures I had recommended over a year before, in 1961! But that was not to be, either then or even till this very day.

(9)

Some two years later in October, 1964, the department published the final version of PRP#12 in RR64-6. The purpose of the report was to determine the maximum cement alkali-content that could be combined with the reactive cherts without producing excessive expansion (defined as less than 0.1% per year) in the C227 mortar bars. An effort was also made to determine if various admixtures could effectively reduce the overall expansion problem. In addition, three more working groups of cherts were tested. All testing was done by departmental personnel. The cement used for the C227 tests contained an alkali content of 0.79%. The report concluded that 1 of the three new cherts tested under C227, produced excessive expansion of 0.10%.

The overall conclusions of the report indicated that at least 6 of the 9 working groups of cherts were deleteriously reactive when combined with cements containing more than 0.7% alkalies. None of the admixtures tested proved to be effective in controlling the reaction. No evidence of alkali-aggregate reactions were found in the field concrete.

The report recommended that all cements be tested for alkali

content. When the alkali content is less than 0.7% no restriction would be placed on the aggregate used. When the cement alkali content exceeded 0.7% the cherty aggregates would have to be checked under ASTM C289 and C227.

In spite of the shortcomings of the report itself, the conclusions reached and the recommendations made, this report was an extremely important one. It recommended taking the very first small steps in the direction of controlling at least part of our alkali-aggregate problems.

George McAlpin (10) our Deputy Chief Engineer, In Charge of Technical Services at that particular time, recognized the importance of the report's findings. In a memo dated September 24, 1964 to our Chief Engineer Bob Sweet, he recommended controls be adopted by the department to preclude the occurrance of alkali-aggregate reactions in New York State concrete incorporating coarse aggregates from the cherty Onondaga Limestone Formation.

His recommendations were never put into effect! The same fate awaited Harry McLean's 1971 recommendations.

I implied earlier that the department's final report on the "Deleterious Properties of Chert" contained several serious errors of omission and commission. It is important that we understand what they are, since these errors have exerted considerable influence over the thinking and actions of the department from that time on.

(11)

Probably the single most serious error in the entire report was the determination of 0.7% as the safe upper limit for cement alkalies. Numerous agencies then as now, accepted and adopted the nationally established ASTM limitation of 0.6%. Indeed, several agencies found it prudent to drop the requirement to 0.5% and even 0.4% upon discovering their plight. Only years later did they decide to raise the upper limit; and then only to 0.6%.

The department developed the 0.7% figure from this chart on page 13 of the report.

The first thing to be understood, is that the test values we see here are not, I repeat, not the results of one series of tests, run at one particular point in time, by one group of individuals, for the express purpose of determining the safe upper sodium and potassium cement-alkali content that can be combined with the specific cherts. Rather it represents a conglomerate of values obtained from Dunn and Ozols' work of two years earlier and values for the three cherts tested by the department under their admixture research series. As interesting as the results might have been, it hardly seems appropriate that they would serve as the basis of a statewide cement alkali limit.

The first group at the left hand side of the chart represents the results obtained by Dunn and Ozol two years earlier.

The second group from the left includes the three cherts tested by the Department. Two of the cherts did not produce excessive expansion. The third expanded approximately 0.1%

None of the 4 most reactive cherts included in group I were tested and included in group II.

Groups III, IV, and V represents the values obtained for cherts 57B and 73 from the admixture tests. Only one of the six values included in these three groups represents the chert tested at its pessimum. The alkali contents of the cements used in Groups IV and V are indicated to be 0.44 and 0.45% respectively. The difference between the two cements is certainly not significant and poses the question why it was done.

Using the rather misleading information given in the chart, the department fit this (12) curve to it as seen on page 15 of the report. Note that the curve values are the reverse of the chart values. It is a strange curve. It indicates that all cherts expand approximately 0.03% when combined with cements containing between 0 an 0.6% alkalies. In the 0.6 to 0.9% range the rate of change of the curve accellerates rapidly indicating that infinite expansion takes place as the alkali content of the cement approaches 1.0%!! Let it suffice to say that neither alkali-silica reactions as in this case, nor alkali-carbonate reactions behave in this fashion.

The only purpose served in putting the data together and interpreting it as it was, appears to be the unconscious (13) desire to support the opinion expressed on page 14 of the

report which says;

> ".....The important point illustrated here is that Onondaga cherts may cause expansion in the mortar-bar test only when the alkali content of the cement is considerably higher than the 0.6% normally regarded as producing deleterious expansion with reactive aggregate. This implication has partially been substantiated in the field as shown by the results of a field survey which will be discussed in another section of this report. Briefly that survey indicated that although cherts have been commonly used with cements having 0.7% alkalies, no deleterious expansions have occurred....."

This statement reflects the earlier statement made on page 8 (14) of the report which says;

> ".....Cements 3,4 and 5 used in this series(sic: the admixture test series) had alkali contents of 0.44, 0.45 and 0.70% respectively. These alkali contents are typical of those normally encountered in cements used for New York State construction....."

It is difficult to understand how this statement can be justified. The department has never had a specification that required our cements to be tested for alkali contents. Where did the data come from? If they were obtained from the records of the cement manufactures and not from our own laboratory, I personally would have been reluctant to make use of it.

(B)

It is also puzzling to me why no importance was attached to the fact that the alkali content of the Natural Cement used as an admixture in that series of tests was 1.21% as given on page A-1 of the report. Until they were phased out, in the late '60's, Natural cements were used together with portland cements on a 1 to 8 basis in our structural concrete mixes. I am also puzzled as to why the department believed that

the natural cement would act as an inhibitor to the alkali-aggregate reactions being investigated, when the natural cement contained more alkalies than the portland cement being used! The field survey made in conjunction with this report, was conducted under PRP# 24. We will review this report in detail later on. On page 17 of RR64-6, it states that the field survey involved some 64 structures incorporating Onondaga cherts. All the structures were air-entrained with the majority of them between 1 to 6 years old. In addition, some 100 lane miles of concrete pavement between 8 and 11 years old were examined. Although numerous examples of alkali-aggregate reaction features were noted, such as map cracking, pop outs, etc., they were invariably explained as being caused by de-icing salts, freeze-thaw forces, shrinkage, etc. In the case of a section of the State Thruway pavement between Syracuse and Canastota investigated by the department the report says;

> ".....Spalling at the transverse joints was particularly severe in three successive sections of the New York State Thruway between Canastota and Syracuse. All were constructed in 1950 with Onondaga aggregate from the same source containing less than five percent chert. Nevertheless, the chert has been regarded by some engineers as having caused the concrete to "grow" and spall at the joints. When inspected, however, the joints did not appear any "tighter" than the transverse joints in other pavements included in the survey. Moreover, there were no signs of map cracking or other evidence of an alkali-aggregate reaction. Considering the small amount of chert contained in the aggregate, it is concluded that the distress is due to other factors....."

Had the investigator thought about the problem in a little more detail, he may have reached a different conclusion. Transverse pavement joints are actually contraction joints and as such allow no room for expansion of the concrete pavement; therefore,

all transverse joints would look the same whether the pavement was expanding from alkali-aggregate reactions or not. The best place to look for evidence of pavement expansion is at the expansion joints near the structures. We'll see numerous examples of pavement expansion problems later on. The normal way for contraction or transverse joints to fail when they are under compressive stress is by spalling or crushing which is exactly what the investigators found in the field.

Finally, it is rather surprising that no effort was made during the field survey portion of the report, to obtain cores from any of the pavements and structures exhibiting distress characteristics similar to those associated with alkali-aggregate reactions. It is however, in keeping with the overall tone of the report which tends to give one the impression that the department just could not believe alkali-aggregate reactions were possible in New York State.

Although New York State has failed to associate our Onondaga cherts with alkali-aggregate activity in our field concrete, this does not seem to be the case in Canada. In an article published in 1966 in HRR#124, (15) Ingham and Koniuszin discuss problems in Canadian concrete incorporating cherts from the Bois Blanc Formation, the lower most Devonian present throughout much of southwestern Ontario, Canada. They note that the Bois Blanc Formation is similar to the lower Onondaga Formation of New York State.

The concrete distress is believed to be attributable to alkali-silica reactions. The severe pattern cracking of the concrete seen in the photo on page 51 of the report, is very similar to distressed New York State concrete incorporating cherty aggregates from the Onondaga Limestone rock formation. At the bottom of page 50 they make an interesting statement;

> ".....Thin sections indicate alkali-silica gel occurs in minor amounts in these concretes but surface exudations rarely show more than a trace amount of silica....."

The point here is that alkali-silica gel deposits are often very difficult to locate and identify. Because of the importance attached to the identification of reaction products in distressed concrete samples by the Department, it is a point I will emphasize throughout this report. Over the years the Department has insisted that unless gels can be found in the concrete, they will not conceed that the alkali-aggregate reaction may have taken place.

Besides the proven reactive siliceous Onondaga cherts, I consider at least the siliceous Pennfield member of the Lockport Dolomite rock formation of western New York as reasonably suspect because of its association with so many of our similarly distressed bridges. Back in 1958 Richard C. Mielenz in HRB publication 616, listed siliceous dolomites among the most important deleteriously reactive rocks. This major concrete aggregate source has never been tested for alkali-silica activity!

(17)

Late in 1963, RR 63-3 entitled "Characteristics of Various Aggregate Producing Bedrock Formations In New York State" was completed by Dr. James Dunn for the department. The rock formations studied were;

1. The Nedrow Member of the Onondaga Formation.
2. Five members of the Manlius Formation.
3. The Cobbleskill Calcareous Dolomite Formation.
4. Six members of the Lockport Dolomite Formation.
5. The Pamelia Limestone and Dolomite Formation.
6. Catskill Graywackes.

A total of 79 fifty pound block samples were obtained from various quarry faces. Each sample was selected as carefully as possible so as to be truely representative of <u>each megascopically distinct unit</u>. Dunn recognized the shortcomings of this sampling procedure but considered it a reasonable compromise in view of the costs involved, time pressures and anticipated utilization of results.

The rock formations studied in this report covered a wide range of chemical and mineralogic types. They varied from almost 100% calcite to almost 100% dolomite, from sandy carbonate rocks, to clay-rich rocks. Some of the more important findings of the report are as follows;

1. Two rock cylinders produced excessive expansion (1.3%) when immersed in a 1 molar NaOH solution for 8 weeks. One cylinder was from the Beekmantown member of the Theresa Formation of Northern New York. The other cylinder was from the Pamelia Limestone and Dolomite Formation of the Black River Group that extends into Kingston, Ontario, Canada. Both the Beekmantown and the Pamelia are argillaceous dolomites.

   In neither case was Dunn able to prove that dedolomitization had taken place since he could not verify the presence of Brucite (MgOH) by x-Ray analysis.

(18)

2. On page 167 he makes additional comments on the results of the NaOH tests,".....14 of the 15 most reactive are dolomites and many are siliceous..... The consistently large pH changes in the Oak Orchard.....and the Pennfield.....members of the Lockport formation may be significant and suggests a likelihood of some sort of "alkali reaction" with solutions in portland cement....."

   On page 149 he recommends ".....All siliceous rocks, dolomitic or argillaceous rocks,should be tested for chemical reactivity....." This has never been done.

3. On page 146 Dunn lists several rocks other than the Beekmantown and Pamelia that he considers chemically suspect. These include both the "C-Unit" and the Eramosa Members of the Lockport Formation, parts of the Elmwood member of the Manlius Formation, as well as the Clark member of the Manlius Formation.

Clearly, Dunn had considerable reservations about the chemical activity of many of the aggregates studied.

Before leaving this report let me outline the testing technique (19) used by Dunn to determine the potential chemical reactivity of the tapered ½" by 1" or 2" dolomitic rock cores investigated under RR63-3.

> ".....When the sample had attained a constant length as indicated by a length change of not over 0.1 to 0.2% for one week, the water was poured off and replaced with 1.0 Molar NaOH to cover the sample. The sample was again measured at weekly intervals until the significant expansion stopped, or the sample had shown no expansion after five (5) weeks. Significant expansion was considered to have ceased when the rate of expansion declined rapidly....."

In light of todays knowledge, Dunn's work involving the testing of many New York State argillaceous dolomitic limestones for chemical activity can only be considered as one very small step in the right direction.

Much has been learned about alkali-carbonate reactions since Dunn completed his work in 1963. Many investigators throughout this country and in Canada, have made exhaustive studies of numerous carbonate rocks of the Ordovician, Silurian and Devonian systems.(20) Here in New York State, these rock systems are for today's purposes, best typified by the Pamelia (Ordovician); the Lockport (Silurian); and the Onondaga (Devonian). It is reasonable to believe that if other agencies have experienced problems with aggregates from these rock systems, we too may be experiencing the same problems. Dunn's two reports strongly suggest that this is the case.

Over the years, agencies such as the U.S.Corps of Engineers, have developed criteria for the recognition of potentially harmful reactive carbonate rocks.(21) Bryant Mather in the same NRMCA 1975 report mentioned earlier states it as follows;

> ".....a) When petrographic examinations are made according to CRD-C127 of quarried carbonate rock or of natural gravels containing carbonate-rock particles, adequate data concerning texture, calcite-dolomite ratio, the amount and nature of the acid-insoluble residue, or some combination of these parameters will be obtained in order to recognize potentially reactive rock. Rocks associated with observed expansive dedolomitization have been found to be characterized by fine grain size (generally 50 microns or less) with the dolomite largely present as small, nearly euhedral crystals generally scattered in a finer grained matrix in which the calcite is disseminated. The tendency to expansion, other things being equal, appears to increase with increasing clay content, from about 5 to 25% by weight of the rock, and also appears to increase as the calcite-dolomite ratio of the carbonate portion approaches 1:1.
>
> b) Samples of rock recognized as potentially reactive by petrographic examination will be tested for length change during storage in alkali solution in accordance with CRD-C146(ASTM Designation C586). Rock characterized by expansion of 0.1% or more by or during 84 days of test by CRD-146 shall be classified as potentially reactive.

c) If adequate reliable data are available to demonstrate that concrete structures containing the same aggregate have exhibited deleterious reactions, the aggregate shall be classified as potentially reactive on the basis of its service record....."

In essence, Mather outlines three logical steps; a) try to recognize problem carbonate aggregates by their physical and chemical make up; b) test the ones that are suspect; c) classify aggregates as reactive based on their service records if the record warrents it. The first step in the process is by far the most difficult.

It implies that the examiner is well qualified to perform the examination, and that he, or she, has the necessary equipment to perform the examination in the detailed and meticulous manner it requires. Even more important prehaps, is we must make sure we understand that "step one" in no way restricts the petrographic makeup of reactive carbonate aggregates. If you consider it carefully you will see it only offers guidelines for the petrographer. We will appreciate this point a little better later on.

The second step, a straight forward testing procedure, is simple to understand. The important point, however, is that it contains a specific limitation on the expansion of the rock cylinder in a set time period. The ASTM spec fails to do this. Even the U.S. Corps of Engs. test procedure may have to be modified for some of our New York State aggregates, as we will see later on.

The third step, the classification of aggregate sources on the basis of their service records, is the simplest of the three. In essence, this is what we are doing today. If our field concrete exhibits deleterious alkali-aggregate characteristics, then the related aggregate sources must be deemed reactive. It is totally illogical and naive to insist the aggregates can not be reactive because they aren't supposed to be! The greatest difficulties arise in identifying individual chemically reactive rock layers indigenous to otherwise innocuous lithologic formations.

On pages 161 through 164 of RR 63-3, Dunn includes the Normative Analyses of 87 rock samples. It includes rocks that vary from almost 100% dolomite to 100% calcite; from sandy to clay rich carbonate rocks. His work, extensive as it was, is not sufficiently accurate nor detailed enough to permit us to assign potential reactivity values with any reasonable degree of certainty to the examined lithologic rock formations. Indeed, the sampling procedures followed, precluded the inclusion of many transitional carbonate rock layers that may well be more reactive than the sampled "typical rock types"!

With the wide range of New York State carbonate rock types to chose from, it is little wonder that Dunn found two samples that produced excessive expansion when immersed in NaOH. It is rather surprising he did not find more than just those two,

particularly in light of the experiences of our Canadian neighbors who utilize lithologically similar carbonate rock formations.

(22) HRR 353

One Canadian investigator, Mrs. Ludmila Dolar-Mantuani, has been investigating various carbonate rocks for almost 15 years! At the time her article entitled "Late Expansion Alkali-Carbonate Rocks" was published in HRR #353 in 1971, she had been testing rock cylinders from the Black River (Gull River) Group of the Middle Ordovician System in Ontario Canada for more than 7 years in a 1 Molar NaOH solution. This is the same rock formation that produced Dunn's expansive Pamelia sample, from northern New York.

Her 1971 article was an extension of her earlier work published in 1964 in HRR #45. It was then (23) HRR 45 that she first classified carbonate rocks from the Black River (Gull River) Group, as either nonexpansive, minor expansive, or as an early-major or late-major expander. The categories were based on the amount of expansion shown by the individual rock cylinders regardless of the time period involved. Late and early major expanders were separated on the basis of their expansion curve characteristics.

(24) HR 353

Carbonate rocks were classified as non-expanders if they failed to expand more than 0.1%.

Those that expanded more than 0.1% but less than 0.4% were classified as minor expanders. Please note that the term "minor" does not mean the rocks are innocuous.

Major expanding rock cylinders are identified as those that expanded more than 0.4%. The difference between an early-major and a late-major expander can be seen in their graph curves. Late-major expanding rocks characteristically contract for very lengthy periods of time, commonly exceeding 6 months or more, before they begin to expand. Dunn's testing procedures would not have detected carbonate rocks in this classification.

Mrs. Mantuani points out that only the early-major expanding rocks were fully capable of detection in the first 5 weeks of testing. You may recall that Dunn used a 5 week test period. This is the only group that did not significantly contract initially.

Some minor expanders contracted for more than 12 weeks before expanding, hence, Dunn's testing procedure would not have detected this problem either.

Mrs. Mantuani makes the important point that minor-expansive rocks, as well as both early-major and late-major expansive rocks may be found in the same quarry! And furthermore, all three types may have the same range of petrographic properties!

However, it is worth noting that most late-major expanders were characterized by a dolomite content of between 75 and 85% of the carbonates, and an acid-insoluble content of between 20 and 50%. (25) Ternary Chart + also exceptions from Iceland

As I have already noted, the rocks tested by Mrs. Mantuani (26) as well as the Pamelia and Beekmantown formations tested by Dunn, form part of the Ordovician Rock System. The Ordovician system extends from Canada into New York State and is quarried in Iowa (27) as well as in Virginia. Both Iowa and Virginia have experienced expansive problems in concrete incorporating aggregates from the Ordovician system.

(28) Finally, in an article published in HRB bulletin #275 in 1960, Swenson and Gillot describe some of the characteristics of distressed concrete containing expansive aggregates of the Black River Group in Ontario Canada. They indicate the surface of the concrete is heavily cracked. The interior of the concrete contains rimmed aggregates. Some of the rims are narrow and some are quite broad and well defined. Many of the sockets from which aggregates had been removed showed slight brownish stains. Freshly broken mortar surfaces had a slightly chalky appearance. Only a very small quantity of silica gel could be found in the distressed concrete.

Most of these features are visible in the samples of distressed concrete I have here today.

(29) Before proceeding on to our gravels, let me mention an accelerated test method advocated by P. Smith of Canada, for testing reactive carbonate rocks. By using a fortified cement of 3% alkali content to make 3"x4"x16" concrete prisms, he was able to detect expansive carbonate aggregates in 21 days time! Smith's test procedure should be employed by the Department at least in the early stages of any future carbonate rock investigations.

The gravels of western New York constitute another major source for concrete aggregates in this geographic location. To my knowledge, no investigations have ever been made by the department to determine the potential reactivity of our gravels. Departmental records indicate these gravels contain Graywackes, Quartzites, Granitics, Limestone, Dolomite, Chert, Siltstone, Red Sandstone and Calcareous Sandstones. Petrographically, they reflect the influence of the Canadian aggregates to the north, and of our own state bedrock formations. Quite naturally, concrete incorporating our gravel aggregates, deteriorates in the same manner as concrete utilizing aggregates from our bedrock formations. It is reasonable to expect that both alkali-silica and alkali-carbonate reactions can occur in concrete incorporating gravel aggregates.

(2)

In an article entitled "Alkali-Silica Reactive Rocks In The Canadian Shield", published in HRR #268 around 1969, Mrs. Ludmila Mantuani discusses the deleterious expansion of concrete incorporating sands, gravels and rocks in an area some 200 miles north of Toronto, Canada. This was the first time alkali-silica reactions had been reported in the Province of Ontario, or in the Canadian Shield. ASTM C289, the Quick Chemical Test, failed to indicate their reactive nature.

The reactive aggregates were identified as varved argillites, graywackes and quartzites. Field concrete samples contained copious white deposits of calcite and partially dehydrated silica gel. Gel deposits were most frequently associated with the varved argillite particles, rarely with the graywackes, and hardly ever with the quartzites. The (3) gel deposits were colorless

and transparent, or white and porcelaneous, concentrated primarily in the abundant voids in the concrete. In all cases the gel deposits were difficult to detect.

(32) ← (Show for comparison purposes - switch back to 31 & again to 32)
.58
.67
.31
.76
DNT.

She points out that a mortar bar containing 7.5% air voids, had half of the voids filled either partially or completely with gel before final cracking took place. This is the first firm evidence I encountered that supported my long held belief that air-entrainment may slow up the resultant distress of alkali-aggregate reactions, but it will not prevent it from taking place eventually.

Let me take a moment now to quickly sum up what has been established up until this point in my report. It has been shown that almost all of the Onondaga cherts are reactive according to NYSDOT own research. We also have every reason to believe that at least some of our dolomitic limestones are reactive, as are our siliceous dolomites and gravels, especially those in the western sections of the State. From what we have seen so far of our distressed field concrete, its physical appearance closely resembles that of the Canadian alkali-aggregate affected concrete.

If we knew precisely what maximum cement alkali content could be tolerated by our reactive aggregates without producing deleterious expansion in concrete incorporating these aggregates, and if we knew for a certainty that cement containing alkalies in these quantities has been used in conjunction with the reactive aggregates to produce concrete in New York State, we could in good

conscience conclude that in all probablity alkali-aggregate reactions have occurred in New York State concrete.

To begin with then, it should be perfectly obvious to all of us that we have no idea what the critical alkali content must be; for the simple reason that not all reactive aggregates have yet been detected and tested! Only then will we be able to set an alkali limit for the aggregate in question.

But there are some known facts that can help us in this dilemma. The first thing that comes to mind is that any number of agencies, states and countries, have found the ASTM limit of 0.6% more than adequate for the task. In some very exceptional cases, lower limits have been needed to control the problem, and it is possible that this may be the case for us here in New York State. But if that is true we would, most unfortunately, start looking for cements that exceeded a much lower critical alkali content. I used the word "unfortunately" for the simple reason that more cements will exceed the lower limit, say 0.5%, than will exceed 0.6%, thereby making the problem more difficult to control.

Should we be fortunate enough to eventually determine that our problem can be satisfactorily handled with cements containing more than 0.6%, say 0.7% as was hastily and wrongly determined under RR 64-6, our cement problems would be lessened for the same obvious reasons.

In view of the fact that we haven't any solid evidence refuting the assumption that the maximum safe alkali limit is anything other than the worldwide accepted 0.6% limit, it is reasonable to accept 0.6% as the critical alkali limit at least on an interim basis.

As noted earlier, the department's own research flatly states that State cements with alkali contents of 0.7% have been commonly used with reactive aggregates! This implies that cements with more than 0.7% alkalies have been used less commonly!

And why not? Cement manufacturers are in business to make a profit. Would you supply a Cadillac if the customer was happy with a Vega? Let me say again, the department has never had a general cement specification that limited the alkali content of cements to be used with reactive aggregates. MacAlpin tried in 1964 as did McClean in 1971, but nothing happened. Without this specification requirement the department has no legal means of rejecting State cements on the basis of alkali content!

It would appear that even the actual determination of the correct alkali content of a given cement is open to debate if what we

read in Appendix F of Dunn and Ozol's interim report on "Deleterious Properties of Chert" is typical of what may happen. It states on page F-1 that the alkali content of the test cement was reported to be 1.06% by the supplier, but was redetermined to be 0.89% by the State! A difference of almost 20%. It immediately raises the question as to who was right, and why such a large discrepancy occurred. If neither the supplier nor the State was wrong, which is also a possibility, prehaps it indicates the variation that can occur in any given cement grind.

In this regards, let us consider the comments of Ozol and Newlon in an article entitled, "Bridge Deck Deterioration Promoted by Alkali-Carbonate Reactions", published in TRR#525 in 1974. On page 56 of the report they say;

> ".....plant analysis supplied by the cement producer for the period of construction, indicate a total alkali content between 0.45 and 0.55 percent expressed as Na_2O equivalent. In addition, data from random samplings from various construction projects during this period .....show that 80% of the samples from the cement source were between 0.40 and 0.60 percent total alkalies. The remaining 20% were greater than 0.60% alkalies, although in general the cement would conventionally be referred to as "low alkali"(sic; by the cement companies)....."

STOP skip if I am running late in presentation. Pgs 35, 36, 37

If we are truly to understand and appreciate our alkali-aggregate problems, we must have some basic knowledge of cement manufacturing problems. Contrary to the ideas of many laymen and more knowledgeable departmental personnel, the cement manufacturing process is considerably less than an exact mathematical science! It involves the manipulation of calcareous and argillaceous materials that are quarried then crushed to a predetermined fineness, then combined on the basis of their chemical compositions, and run through a mixing device into a calcining unit where the mixture is heated to incipient fusion to produce a clinker containing the desired chemical composition. The clinker may be ground with the aid of certain additives to produce a finished product with other desired characteristics.

It is small wonder that the final product is subject to some amount of variation! The varying nature of the raw calcareous and argillaceous ingredients pose a considerable problem to the cement chemist as it is imperative that he maintain certain ratios of the raw material ingredients as constant as possible if the final product is to contain the desired qualities.

(33)

PRP #10 entitled "Uniformity of Cements" was published by the (34) department in 1962. The study was undertaken to determine just how much our cements do vary. The statistical data upon which the conclusions of this report were based, were obtained from the records of the State of New York, the State of Penn. and nine (9) selected cement producers.

Although this research project was undertaken during the same time period that the department was investigating our Onondaga cherts, no information was collected and included in the cement report as to the range of the alkali contents of the cements studied. One might conclude from this, as I have, that the department did not believe alkali-aggregate reactions were of any consequence in our New York State concrete mixes, and they were only interested in comparing these cements with their current cement specification requirements.

In the section of the report dealing with the cement manufacturing process and the type of fuels introduced in the cement kiln during the calcining operation, on page 40 it states;

> ".....Pulverized coal is used extensively in the Northeastern states, and exclusively in the nine subject plants. In his discussion of the effects of coal on the burning process, Lea (10) states:
>
> The ash of the coal used for firing a rotary kiln combines with the raw mix during burning and thus causes some alterations in its composition. The ash consists mainly of silica, alumina and ferric oxide. It is apparent that the coal ash causes quite a considerable change in the composition of the clinker. In practice the composition of the raw mix is adjusted so as to allow for this change. It is commonly found that about two-thirds of the ash is taken up by the clinker and about one-third passes out of the kiln with the gases....."

At the time Lea published this information back in 1956, he may not have appreciated the importance of the sodium and potassium contents of coal as did other individuals such as Blanks and Kennedy. If he had, he would surely have included the information that they too combine with the cement clinker, and thereby increase the alkali content of the cement above the quantity inevitably contributed by the argillaceous and calcareous raw materials.

With the advent of present day energy problems and increasing demands for better air-pollution controls, we can only expect that cement alkali contents will rise, as various manufacturers switch from scarcer fuels into coal and attempt to conserve energy costs while minimizing air-pollution problems by returning flue gases during preheater operations.

Canadian cements are notorious for their high alkali contents. They normally run between 0.8 and 1.0%. These cements are extensively used in western and central New York in combination with our reactive aggregates.to produce substantial quantities of our commercial concrete.

Too sum up then everything we have discussed concerning the alkali content of State cements, both commercial and DOT approved, we can reasonably conclude that our State cements commonly exceed the ASTM limit of 0.6% alkalies. And therefore they are fully capable of producing alkali-aggregate reactions in much of our State concrete.

As we have already noted, the restriction of cement alkali contents may create serious problems for some cement producers. Indeed, some may be unable to manufacture cements with less than 0.6% alkalies. For these reasons low alkali cements sell at a premium. Today, regular cement sells for about $8 a barrel. Years ago, low alkali cement cost 50¢ more a barrel. Even if it costs 20 times that now, it is still cheap insurance. N.Y.State concrete using 1½ bbls of cement per yard costs approximately $300 per yard to place and $500 a yard to repair. What these costs will be 15 years from now, is anybody's guess.

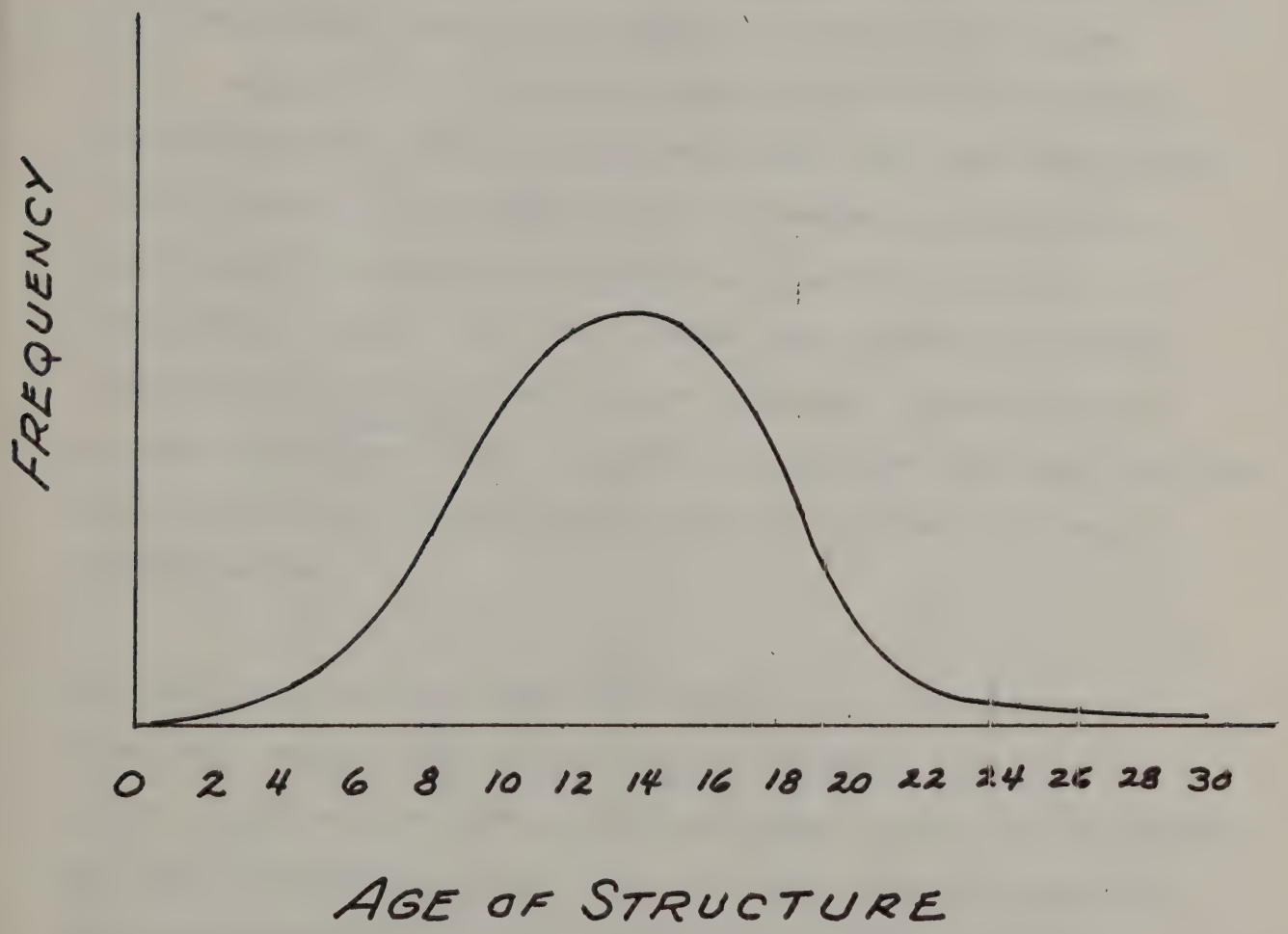
And now I would like to go into the subject of identifying alkali-aggregate type reactions in the field, in a little more detail than what has already been noted. (35) The form of concrete deterioration seen in this slide of a reinforced concrete pipe manufactured in 1966 incorporating coarse aggregates from the Onondaga Limestone formation near Phelps, N.Y., is typical of the concrete distress we are considering here today.

The surface of the concrete is severely cracked. The cracks are quite narrow, seldom exceeding 1/8". Heavy exudations issue from the cracked portions of the concrete. A distinct tanish stain, similar to the color of a deer's hide, covers much of the affected area. No popouts have developed in this example, but they do occassionly show up in some of our other concrete.

If we break off a piece of the distressed concrete and let it dry out for a moment or so, we find the interior contains white chalky deposits and many rimmed aggregates. Small voids in the concrete are often lined with a gray lustrous material. Quite often, particularly in our gravel concrete, the socket from which reactive particles have been removed contain a brown stain similar in color to the surface stains. While the stain on the surface is powdery in appearance, the socket stains are sometimes filmy and quite flexible when first detected.

Proof that the distress was due to the occurrence of expansive forces within the shell of the concrete pipe, will be given a bit later on.

RECOGNITION CURVE
ALKALI-AGGREGATE REACTIONS



(36) Recognition curve

By and large, central and western New York alkali-aggregate reactions are not recognizable in our field concrete, at least not to the casual observer, until the concrete is between 5 and 20 years of age, with the majority recognizable at or around the 12 to 16 year mark.

Of all the alkali-aggregate manifestations we have just discussed, I find the (37) tan stain to be the most interesting. In the overwhelming majority of cases, it is the first sign, visible to the unaided eye, that positively indicates alkali-aggregate reactions are occurring. The stain may appear on the surface of the concrete as a blemish, either before any visible cracking is noticeable, or as the cracking is progressing. It is found on vertical and horizontal surfaces subjected to cycles of wetting and drying. The most vividly colored stains usually occur on our southern exposure concrete. The stain is associated with reactions involving our gravels, cherts and dolomites.

To the best of my knowledge no one has ever identified the chemical nature of the stain or where it comes from. I suspect it may be iron that is released from either clay particles such as iron-serricite, or from iron compounds attached to dolomite crystals. I first associated the stain with our alkali-aggregate problems back in 1961. Since then I refer to it as the "Pratuch Effect!"

I do not claim to be the only person to ever associate tan or brownish stains in and on concrete, with alkali-aggregate reactivity. We've already noted their detection in Canadian concrete. And I believe Bryant Mather referred to them as brown tarry spots while studying some mortar bars containing reactive fine aggregates. (38) Calvin C. Oleson wrote about them back in 1963 in a PCA report entitled, "Abnormal Cracking In Highway Structures In Georgia & Alabama". Prehaps C.A. Carpenter, (39) Acting Chief Materials, Research Division, BPR had the same brown stains in mind when he referred to them in his letter to Malcom Graham dated Dec. 3, 1963. Carpenter referred to them as "Shippey Spots", and noted that they were invariably associated with alkali-aggregate reactions in the southeast portion of the United States.

(40) The presence of so many rimmed aggregates in our distressed concrete is positive proof that chemical reactions have taken place while the aggregate was embedded in the concrete mass. In the case of gravel aggregates, there is the possibility the rims were present before the aggregate was incorporated into the concrete, but as (41) Bryant Mather points out, there is no ambiguity about the presence of rimmed crushed stone aggregates in concrete. They can only have resulted from chemical reactions after the crushed stone particle was introduced into the concrete mix.

On several occasions earlier in this report I mentioned that the department has failed to recognize our concrete deteri-

oration problems as alkali-aggregate related because the department could never find silica gel or gel relics in any of the distressed concrete. Again as Bryant Mather points out, silica gels are also positive proof that chemical reactions have occurred in the concrete. However it is still difficult for me to understand why the department took such an intransigent stand in this matter. We have already seen that several expert investigators using the most sophisticated equipment, such as electron probes, experienced considerable problems in locating and identifying silica gels in field samples of distressed concrete.

The department's position is even more puzzling when we read on page 3 (42) of the final report on the "Deleterious Properties of Chert";

> ".....Because of operational problems experienced in preparing and analyzing the thin sections, the results were not entirely satisfactory and positive identification of the gel products could not be made. However, there is little doubt that the mortar-bar expansions were caused by the alkali-aggregate reaction....."

There is a serious inconsistency here. How can the lack of silica gels be critical in field samples and only of minimal importance in laboratory controlled mortar-bars? One thing is clear however, the departments' techniques and equipment may be ill suited for the task of finding and identifying reaction products.

The difficulty in locating and identifying alkalic-silica gels, stems from the fact that their physical and chemical characteristics can vary over a wide range. They are affected by the physical and chemical environment in which they are created and exist. Gels may range from a clear liquid to a

hardened scaley material, either white or gray in color, or dull and porcelaneous in luster. Sherwood and Newlon point out that $CaCO_3$ predominates in the X-Ray diffractogram making it very difficult to identify reaction products. Add to this the fact that severe weathering and road de-icing salt attack may alter or even destroy the gels completely. And finally, concrete may crack long before silica gels as such are produced!

It is small wonder silica gels are hard to detect in field concrete.

Expansion of affected concrete is an implicit function of alkali-aggregate reactivity. But lacking data concerning length change measurements of specific concrete units, we will have to look for other proof indicating certain concrete units did indeed expand. In this category I would place jammed or crushed horizontal and vertical expansion joints often exuding compressed joint material; warped and displaced units; blow-ups; bulging and spalling.

L 43 MOM '60

Probably the simplest examples of expansion can be found in many of our concrete pavements in the vicinity of our structures. The tremendous expansive forces generated in our pavements literally tear our bridges apart. In these slides we see only a few examples of what happens to our structures.

MOM '60 → → MOM '60 → → MOM '62 '63 → MOM '54 '68 → → → MOM '54 '68 MOM '54

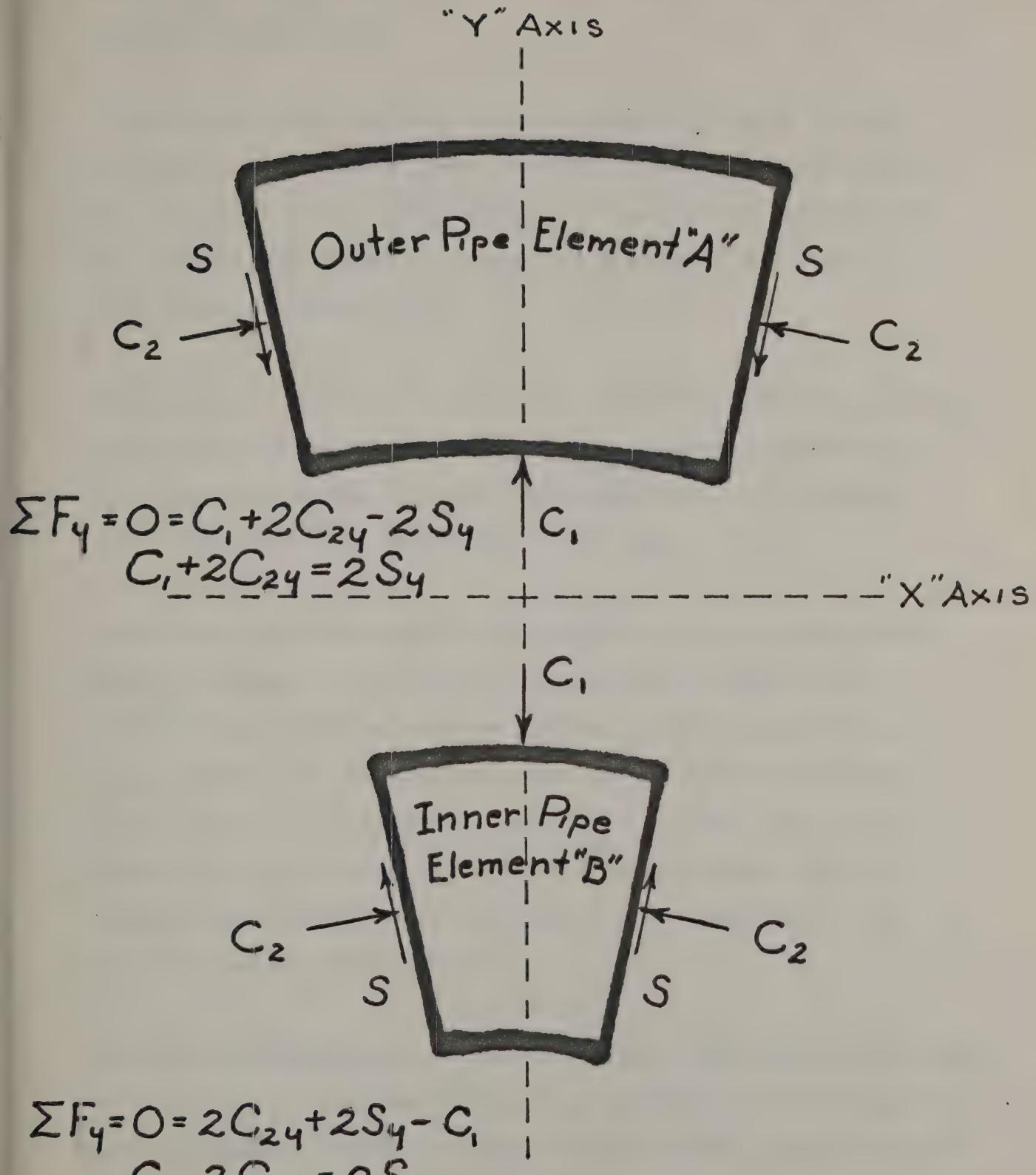
L 44 L 45 L 46 L 47 L 48 L 49 L 50 L 51 L 52 L 53 L 54 L 55 L 56 L 57 R431 [illegible]

While it is quite obvious from these slides that the pavement had to expand in order to produce the destruction we have seen, it is far more difficult to equate our normal structural concrete deterioration problems with the occurrence of similar deleterious expansive forces in the distressed structural concrete.

(58)
This slide of a group of 108" reinforced concrete pipe was taken (59)
earlier this year. The pipe was stored in a field in Geneseo New York since 1965 or'66. They were manufactured in Phelps, N.Y. around that same period of time. The aggregates involved are from the old General Crushed Stone Co. quarry in the Town of Phelps, Ontario Co., quarry no. 4-8R. This quarry contains three members of the Onondaga Limestone formation; the Moorehouse, the Nedrow, and the Edgecliff. All three are cherty, somewhat argillaceous and dolomitic limestones. They are positioned immediately above the argillaceous Cobleskill Calcareous Dolomite Formation.

The concrete deterioration is typical of our structural concrete and does not involve de-icing salts. The steel reinforcing appears to consist of at least two wire mesh cages of 3/0 steel on 2" centers that circle the pipe. The pipe was cast with the tongue end (the top of the pipe as we now view it) down.

Let us assume the shell of the pipe is undergoing a pure compressive stress as would be the case if the concrete was expanding. If we analyze the forces acting on a small Element A at the convex outer most layer of the pipe, we note that equilibrium is overcome and outward movement of Element A will occur, when the summation of the vertical components of the compressive

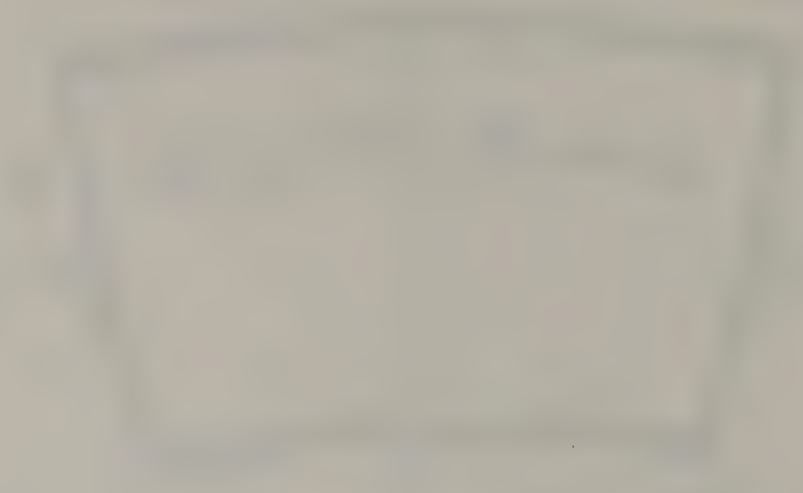


$$\Sigma F_y = 0 = C_1 + 2C_{2y} - 2S_y$$

$$C_1 + 2C_{2y} = 2S_y$$

$$\Sigma F_y = 0 = 2C_{2y} + 2S_y - C_1$$

$$C_1 - 2C_{2y} = 2S_y$$



forces (C_1+2C_{2y}) exceed the vertical components of the resisting shear forces ($2S_y$).

A similar analysis of the forces acting on a small Element B located at the concave inner surface of the pipe undergoing the identical compressive stress, indicates that equilibrium is overcome and outward movement of Element B will occur when C_1-2C_{2y} exceeds $2S_y$.

When $C_1=C_2$, as would be the case for expanding concrete, C_1+2C_{2y} will always be greater than C_1-2C_{2y}; therefore, elements on the outer convex surfaces will always move before the elements on the concave inner surfaces of the pipe.

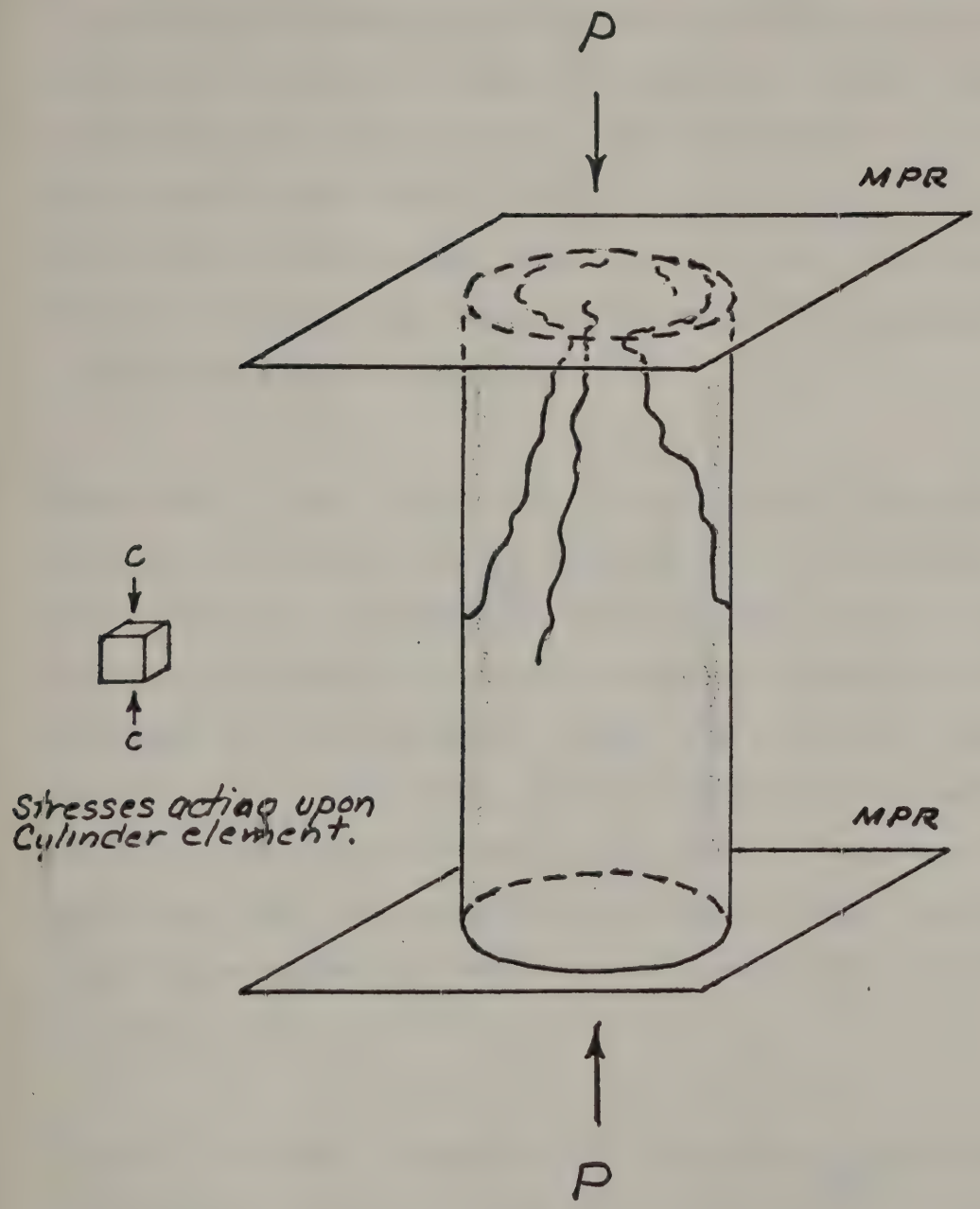
Proof that this oversimplification of the actual complicated forces involved is basically correct, can be seen in this slide (61) of the interior concave surface of the pipe. Although it is exposed to the elements much as the exterior portion of the pipe, it is extremely difficult to find any visible signs of distress. But if we look close (62), we do see that some cracking is evident where the interior is subjected to the greatest amount of sunshine.

The heavy circumferential closely spaced steel mesh reinforcing at the exterior surface of the pipe restricts the deformation of the expanding elements along the individual loops of reinforcing. Hence, we find the cracks tend to occur between

the individual wire strands where the expanding elements are less restrained. The concrete fails in shear at first, in the same manner concrete (63) test cylinders fail when loaded beyond their maximum compressive strength. This spall type failure is often found in structural units in the field that exhibit distress features characteristic of alkali-aggregate reactivity. For example, our round reinforced concrete columns in the Rochester region are often fractured in this fashion. In all three cases mentioned, the first cracks visible to the naked eye are oriented fairly perpendicular to the major planes of restraint.

In the simple case of the plain concrete cylinders the major planes of restraint are located at the two loaded ends. The unrestrained barrel of the cylinder deforms under the increasing loads until the applied loads exceed the inherent compressive strength of the concrete. (64) MON '62 In the case of our concrete columns, two separate compressive stresses are involved; one from the live and dead loads of the superstructure that are transmitted through the column to the footer, and one from the expansive reaction occurring within the column. The main reinforcing steel in the column extends from the footer into the header beam. It too acts to restrain the deformation of the column concrete in the vertical direction, hence we can assign a secondary restraint plane to the effects of the reinforcing steel. These planes can be assumed to be located at the ends of the columns also. Additional column reinforcing in the form of ties, etc., add still another form of restraint and may affect the ultimate concrete fracture pattern that is developed. In general the major restraint planes are located at the ends of the column. (65) MON '62 (66) → (67) →

MAJOR PLANES OF RESTRAINT



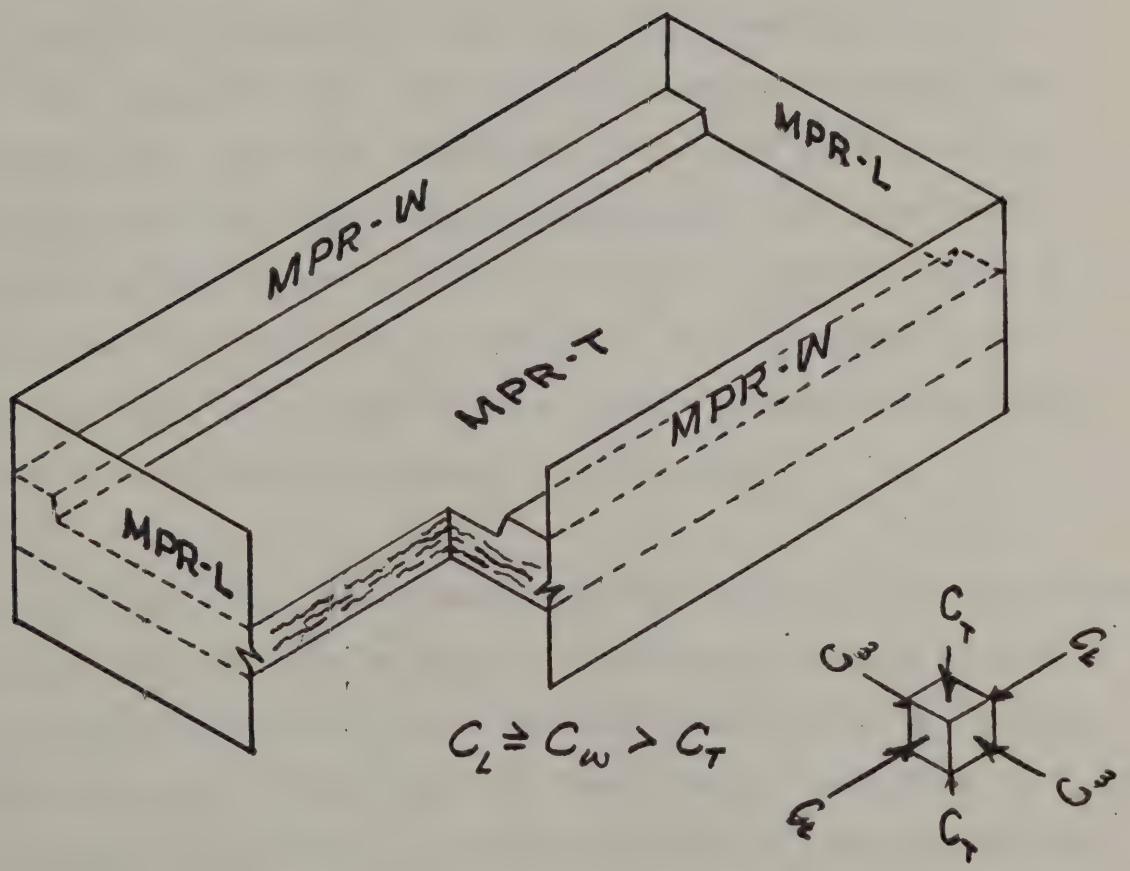
CONCRETE TEST CYLINDER

In the case of the reinforced concrete pipe, we would place the imaginary planes of restraint perpendicular to the circular wire mesh strands. The expansion forces operating within the pipe shell produce bending stresses as well as the already noted shear stresses. The bending stresses are developed as curved pipe elements bulge and deform to accommodate the expansion forces. This results in some of the concrete failing in tension.

Regardless of how the cracks are initiated, they tend to propogate themselves along lines of least resistance. For this reason we find many (68) of them cutting diagonally across the main reinforcing strands, changing direction as the stresses in the pipe shell change. The internal expansion forces, rather than being uniform throughout the entire pipe shell as originally hypothesized, vary in intensity due to localized heat and moisture conditions. Hence, the more exposed areas generally expand at a greater rate than the less exposed areas.

Finally, through the use of the concept of "Major Planes of (69) Restraint", I believe I can explain the delamination of our reinforced concrete decks, that to my knowledge, has never been satisfactorily explained on any other basis.

Major Planes of Restraint Operating On A Simple Span Two-Way Reinforced Concrete Bridge Deck



Delamination Effect

Take any simple span reinforced concrete bridge deck having a length "L", a width "W", and a thickness "T". For the simplest case we will assume that the deck contains two-way steel reinforcing of equal steel area, with one mat located near the top of the deck and the other mat located at the bottom of the deck. We will also assume the deck does not contain any vertical steel such as stirrups, etc.

Under these conditions the primary major plane of restraint will will exist at the ends of the deck. The secondary major plane of restraint will exist at the sides of the deck. And the very minor plane of restraint will exist at the top and bottom of the deck. Any element undergoing expansion in the interior of the concrete deck will find it easier to deform across the thickness "T" of the slab. Since the concrete will fail in shear, the deck will tend to delaminate parallel to the top and bottom surfaces of the deck.

This explanation of delaminating bridge decks answers questions that are unanswerable by other hypothesis. It would explain why we in maintenance often find deck spalls where the rebars are not rusted. It explains why deck spalls occur even when the rebars are covered by 2" of concrete. It explains why the concrete continues to spall from between the rebars when rusting of rebars can no longer be a factor. And it explains why very little spalling (70) occurred on the "Ultimate Strength" designed Elmwood Ave bridge in Rochester for many years (71). This structure is a 4-span continuous reinforced conrete bridge built in 1963 & '64.

The higher stresses carried by the reinforcing steel under ultimate strength design principles, leads to the development of much wider tension cracks in the concrete than normally occur in our structures designed on the basis of straight-line stress concepts. A portion of the research study of this bridge involved a long term investigation of the effects of creep on these wearing surface tensile cracks. For this reason they went unsealed for many years. The section of Rochester in which this structure was built, is one of the most heavily salted areas in the entire County of Monroe!

Until approximately 4 years ago, no spalling had occurred. (72) MON '63 About that time I noticed the appearance of tan stains on isolated fascia surfaces. Since then spalling has occurred; however, as we have seen, it is rather limited at this time. Taken together, all these facts suggest to me that contrary to presently accepted thinking, the rusting of steel reinforcing exacerbated by the use of road de-icing salts, may not be the primary cause of our concrete bridge deck spalling problems! If they were, surely the Elmwood Avenue deck would have failed at a much earlier date. For comparative purposes (73) MON '73 I offer the Rochester Outer Loop decks built in and around 1970 which spalled in less than four years. This is a rather common occurrance in our Greater Rochester Area bridge decks. We have several of these new decks scheduled for extensive repairs sometime in the near future.

Section 5

Over the years the research conducted by the department, invariably concluded that alkali-aggregate reactions have never occurred in our concrete structures or pavements! Any problems we did have were attributed to freeze-thaw failures of a saturated porous cement paste, the lack of a proper air-void system in the distressed concrete and the use of road de-icing salts.

As we have already seen, these were the conclusions reached in RR 64-6, the final report of PRP#12 entitled "Deleterious Properties of Chert", completed late in 1964.

Earlier, in late 1963, the department released RR 63-4, a part of PRP #24. It was entitled, "Investigation of Concrete Deterioration In Certain Bridges In The Rochester, N.Y. Area". Included in the study were the Troup Howell bridge over the Genesee River, the Ridgeway Ave bridge over Mt. Read Blvd., the Ridge Road bridge over Mt. Read Blvd., the B&ORR bridge over Mt. Read Blvd., and the Mt. Read Blvd. bridge over the NYCRR. All of these structures were built in the 1953 to 1955 era. Some were built with air-entrained cement and some were built with regular cement. Many of them used natural cements on a 1:8 basis with regular portland cement.

These were the very same bridges I originally had written about back in 1961 when I first suggested that alkali-aggregate reactions occurred in our State concrete. The department's conclusions failed to give any credence to my ideas. No consideration

was ever given by the Department to the considerable data I had collected relating concrete failures to specific cement acceptance numbers. Unfortunately, subsequent changes in departmental procedures now preclude the investigation of concrete deterioration on the basis of the cements used.

Although RR 63-4 (4) acknowledged the presence of broad rimmed aggregates from the Decew lithology, and thin rimmed aggregates from the Pennfield and Oak Orchard members of the Lockport Dolomite formation in samples of the distressed concrete, they were not considered to be of any consequence. You may remember that Swenson and Gillot had described the rims associated with reactive Kingston Ontario carbonate rock in precisely the same manner. They published their article in 1960, or three years before RR 63-4! Page 20 of RR 63-4 says;

> ".....Neither the coarse or the fine aggregates are of the type that would make them susceptible to the alkali-aggregate reaction....."

Possible dedolomitization effects associated with alkali-carbonate reactions were dismissed on page (5) 19 with this statement;

> ".....The staining that was performed produced no evidence of chemical action....."

As we have already seen, alkali-carbonate reactions are not that easily determined.

On page 4 of the report the "tan stains" associated with the distressed concrete are dismissed as follows; (6) May 54

> "Light brown stains were noticed on some concrete of this bridge as well as others. These stains were noted only in areas exposed to moisture and frequently in association with incipient cracking. No significance was attached to these other than the fact that they indicated the presence of iron compounds in the drainage....."

One would be hard pressed not to believe the Department attributed them to anything other than the rusting of steel! Prehaps they found my evaluation of them difficult to accept, but I would have thought they would have at least considered what D.O.Woolf said about them when he first saw them. He called them the "fried liver effect", and said that similar stains were known to be associated with alkali-aggregate reactivity in the south-eastern section of the country. The Department had requested Woolf's assistance on an entirely different matter, but since the investigators were in the vicinity of Rochester they sought to get his opinion on our Rochester concrete problems. In fairness however, it must be said that Woolf failed to associate our distress with alkali-aggregate reactions as he was unable to detect silica gel in pieces of concrete containing dolomitic aggregates, examined at the site, which as we know now, is quite understandable. Woolf by the way was on loan to the Department from the BPR in Washington D.C.

When Woolf returned to Washington and discussed his findings with C.A.Carpenter, the tan stains impressed Carpenter sufficiently to prompt him to include the following statement in his previously mention letter to the Department;

".....The possibility may still exist that this reaction (sic: alkali-silica) or the alkali-dolomite reaction, has had a part in initiating the distress of the concrete....."

None of these suggestions had any effect upon the Department either then, or later. Our concrete problems were without any reservations, blamed (7) on the lack of proper air-void systems in the distressed concrete.

While the previous report was in the process of being finalized by the Department, I under took another investigation in the summer of 1963 on my own time and at my own expense, to see just how extensive the problem really was. I made a reconnaissance survey of the New York Thruway overhead structures between Buffalo and New York City. I also checked out numerous bridges on Long Island.

I concluded that alkali-aggregate type reactions occurred in many sections of the State but were most severe in the western and central areas of the State! This appraisal of the Thruway structures made some 13 years ago, is substantiated to a considerable degree by an article printed in the Buffalo Evening News on October 28, of 1976. Let me just quote the two lead paragraphs;

".....Of the 750 bridges along the Thruway, the 100 or so between Victor and Buffalo are and have been deteriorating faster than those in any other area according to Thruway engineers.

In 1975, the Thruway Authority spent $4.9 million for 11 bridge rehabilitation projects, five of them in the Buffalo Division....."

Normally these bridges are expected to last at least 50 years or so with normal maintenance. We have already seen examples of good structures much older than those of the Thruway. Most Thruway structures were built in the 1948 to 1955 era! Person ally

I see no reason why our concrete structures shouldn't last for a hundred years or more!

I submitted my 1963 report to my District Engineer, B. F. Perry, who forwarded it on to Albany. Nothing ever came of it. Quite obviously my ideas and findings had no supporters in the main office.

(8)

Late in 1965, RR 65-9 was published by the department. The title of this report was "An Evaluation of Concrete Containing Coarse Aggregate From The Manlius, Lockport & Onondaga Formations In Western and Central New York." These are the same aggregates that had been incorporated in to the Thruway structures between Buffalo and Syracuse that I had investigated and found to be in questionable condition some two years before, and the same structures that the Thruway engineers now say have given them the most problems.

Not only did RR 65-9 fail to find any evidence of alkali-aggregate reactivity in any of the structures; it failed to find any kind of major distress problems in any of the concrete.

(9)

The letter of transmittal that accompanied the report extolled the quality of our State concrete and the virtues of our acceptance procedures. Unfortunately for the New York State Tax Payer it just was not true.

(10)

When the department issued the January 25, 1971 memo seen here, I thought at last we were about to finally solve our problems.

McLean's memo was addressed to all interested parties, and notified them of an impending major change in our cement and aggregate requirements. The intent of the change was to control the use of reactive aggregates and high alkali cements. Except for the higher limit of 0.7% placed on the cement alkali content, it was fairly similar to what I had recommened in 1961, some 10 years earlier! The effective date of the change was to be January 28, 1971. They have never been put into effect!

When I read ERD-73-RR 11, published in early 1973, I thought I at last detected a sign that the Department was beginning to appreciate the fact that something other than the lack a proper air-void system in our distressed concrete may be the cause of our problems. This report, entitled "Techniques For Measuring Air Void Characteristics of Concrete", involved the study of ninety-five 4" cores from early New York State concrete pavements, and 348 cores from ten pavements placed in 1967. The abstract of the report contains the following statement;

> ".....The data indicated that blends of portland and natural cements produced concretes with levels of air content and spacing factors generally superior to those of plain portland cement without air entrainment. However, the outstanding durability of many of both types of concrete pavements studied could not be attributed solely to parameters of the air-void system....."

This is precisely the point I attempted to make earlier in this report.when I said that good concrete features are not necessarily a function of the concrete's air-void characteristics. Prehaps the Department will one day study concrete durability from the aspect of reactive aggregates.

Any hope I might have had that the Department was at least leaning in my direction was quickly extinguished in the exchange of subsequent correspondence.

Section 6

(B) (13) MON '07 Gravel

And now I will run through a large group of slides depicting numerous reinforced concrete structures exhibiting visual characteristics of alkali-aggregate reactivity. All of these structures are in the Rochester region of the NYSDOT. They are arranged by age, with the oldest being built in 1907 and the newest in 1972. I will give the county, the date built and the probable aggregates involved, for each structure. It was common practice in the past to mix aggregates from different sources for economical reasons. Although we would like to think it does not happen today, it still goes on. I believe my identification of aggregate types is accurate and valid, but I will defer to higher authorities.

Please note the similarity of the distress regardless of the rock formation aggregates involved. Keep in mind the influence of the restraint planes and their affect on the ultimate cracking pattern. Note that unreinforced units generally exhibit bigger cracking patterns with deeper cracks, than the reinforced units do.

Refer to slide sheets from Tray 3/slide #13 to Tray 4/slide #42

Give a) Year built
b) County
c) Aggregate

Section 7

Tray #4

(43)

The chart we see here is a compilation of those structures in the Rochester region exhibiting characteristics of alkali aggregate reactivity. The figures are quite conservative since many of our newer structures may not have had sufficient time to develop the visible features we are seeking.

Region 4 Structures Affected By Alkali - Aggregate Reactions

County	Exam.	A-A	%	Aggregates
Genesee	72	57	79	Gravel, Onon.,
Livingston	77	30	39	Gravel, Onon.,
Monroe	361	161	44	Gravel, Onon., Lockport
Ontario	63	43	68	Gravel, Onon.,
Orleans	33	16	48	Gravel, Onon., Lockport
Wyoming	38	18	47	Gravel, Onon.,
	644	325	50%	

Section 8

This next group of slides shows that the problem extends clear across the State of New York. Its boundaries are yet to be determined.

Refer to slide sheets from Tray 4 / Slide # 44 to Tray 5 / Slide # 10

Quickly Give : a) County and mention if sampled
b) Aggregate if possible.

Section 9

The purpose of this group of slides is to point out the problems encountered in the repair of these structures. Many times they are initially repaired at considerable cost only to be torn down completely and replaced by a new unit that soon begins to deteriorate in the same manner.

Prehaps, once upon a time, such extravagant expenditures of the Tax Payers' monies could be overlooked. If that time ever did exist, it most certainly does not exist today!

Refer to slide sheets from Tray 5/Slide #21 to #70

1. Date Slide
2. Date Built
3. Dates Repaired & known Costs
4. County
5. Aggregate if possible

Section 10

TRAY #6

(1)

This next group of slides contains examples of alkali-aggregate reactivity in concrete other than that used by the NYSDOT.

Refer Slide sheets Tray #6 / Slide #1 to #17

(1) County
(2) Date Built?
(3) Costs
(4)

Mention that many political units & private concerns follow NYSDOT specs we are their expert.

Section 11

(19)

This group of slides will illustrate another interesting phenom-enon we touched on earlier. It involves the relatively slow rusting of reinforcing steel in concrete structures thought to be unaffected by alkali-aggregate reactions. Even when the steel in these bridges is exposed to road de-icing salts very little spalling occurs. Some of these structures are quite old and still going strong.

Refer to slide sheets Tray c/slide #19 to #28

(1) County
(2) Date Built
(3) 1955?

Section 12

Before concluding this report, I would like to make a few more comments on other field observations I have made.

Generally speaking I would say the superstructure concrete deteriorates more rapidly than the substructure concrete in our bridges where alkali-silica reactions are concerned. Under these same conditions, concrete pavements expand less rapidly then our superstructure concrete. The larger maximum size aggregate generally used in both our pavements and substructure concrete appears to play an important role in the lower rate of deterioration. The generally cooler and relatively greater saturated condition of our pavements seem also to retard the growth of expansive pressures as far as alkali-silica reactions are concerned. And finally, pavements are generally placed at water/cement ratios significantly lower than those used for bridge superstructure concrete.

In general, the reverse appears to be true as far as alkali-carbonate reactions are concerned; here the larger aggregate produces the greatest amount of expansion in the concrete. Recent Department specification changes permitting the substitution of Class A concrete for Class B & C concrete may prove to be undesireable where alkali-silica reactions are concerned and beneficial where alkali-carbonate reactions are involved. The smaller maximum size aggregate used in the Class A concrete would be basically responsible for this situation.

Finally, coarse aggregates manufactured from blast furnace slag are used extensively in our Buffalo area concrete structures. Severe spalling commonly occurs in these structures. Tan stains, somewhat different from the normal Pratuch Effect, are evident on many concrete surfaces. Hence, it appears possible that alkali-silica reactions may have occurred in these structures. But it is also possible that sulpher from the calcium sulfide, present in most blast furnace slag, may have combined with the aluminates in the cement to produce expansive calcium sulfoaluminate. Several millions of dollars have been spent repairing these structures.

Conclusions

I will now summarize what we have seen here today.

1. A serious concrete deterioration problem exists throughout much of upstate New York. It involves every type of concrete unit including pavements, culverts, bridges, concrete pipes, buildings, retaining walls, etc. The problem is particularly severe in central and western New York.

2. Regardless of the aggregates involved,the distressed concrete exhibits similar physical features.as follows;
   a) Amorphous tan stains either on exposed surfaces or in the interior of the concrete mass.
   b) Rimmed aggregates.
   c) Expansion of concrete members.
   d) Severe cracking of exterior surfaces.
   e) Deposits in some of the voids in the concrete.
   f) Freshly broken surfaces exhibit chalky white materials.
   g) Heavy exudations from fractured areas, usually accompany the distress.

All these features have been associated with alkali-aggregate reactions in various sections of the country as well as in Canada.

3. The air void system of the distressed concrete has only a limited effect, if any, in precluding the occurrence of this type of concrete deterioration.

4. Road de-icing salts exacerbate the deterioration problems, but they do not initiate the distress.

5. Six of nine Onondaga Limestone formation chert groups have been shown to be potentially chemically reactive with sodium and potassium alkalies contained in cement. Two argillaceous dolomitic limestones from the Beekmantown and Pamelia Formations of the Ordovician Rock System have been shown to be chemically reactive. Canadian gravels containing many of the same materials included in New York State gravels, have been shown to be reactive. Siliceous dolomites similar to those of the Pennfield member of the Lockport Dolomite Formation in western New York, have been identified as highly reactive.

6. The Department of Transportation has never had a general specification controlling the use of reactive aggregates and high alkali cement, nor have cements alone been regulated as to permissable sodium equivalent alkali content.

7. All reactive aggreagtes will combine with cement alkalies. Whether or not deterioration follows depends on the presence

of critical quantities of alkalies and reactive rock constituents, plus favorable environmental conditions.

8. The critical alkali content of cements that can be safely combined with New York State aggregates is yet to be determined. The 0.7% figure determined under RR 64-6 is incorrect. In all probability it is much to high.

9. The evidence is overwhelming and indicates that alkali-aggregate reactions of both the alkali-silica and the alkali-carbonate type have occurred in much of our New York State concrete. Some of our fine aggregates may be involved.

10. The reaction has been with us a long time and exists today in our newest structures. Hence, it is clear that any controls attempted by the Department have not worked.

11. If this problem is to be truly brought under control, the Department will have to implement and rigidly enforce strict, explicit and comprehensive specification requirements for our cements and aggregates.

12. Finally, over the years alkali-aggregate reactions have cost the New York State Taxpayer literally hundreds of millions of dollars. Tens of millions of more dollars will need to be spent in the future before this form of concrete deterioration is brought under control.

Recommendations

Some of the recommendations I am about to make are based on the fact that the Department has now only a very limited knowledge as to a) the identities of our Statewide reactive rock types, b) the critical alkali contents of cements producing deleterious expansion in concrete incorporating these aggregates, and c) the maximum percent aggregate or mortar-bar expansion that can be permitted while still maintaining the integrity of associated field concrete. The well known rejuvenating effects of some road de-icing salts, may necessitate stricter than normal limitations on cement alkali contents and acceptable expansion limits in the heavily salted areas of the State. Consequently, normally borderline test results may not be tolerable under all conditions. My specific recommendations are as follows:

1. The NYSDOT general specifications for both portland cements and fine and coarse aggregates, shall be immediately revised to include testing procedures for the determination of sodium equivalent ($Na_2O+0.658K_2O$) cement alkali contents and aggregate reactivity. The recommended tests are ASTM C-33, C-114, C-227, C-289, C-295, C-342 and C-586. Tests C-227 and C-586 shall be modified in accordance with the U.S.Corps of Engineers specifications CRD-C-123 and CRD-C-146 respectively.

2. All carbonate aggregates suspected of chemical reactivity that do not produce excessive expansion in the modified C-586 time period, shall continue to be tested for delayed expansion characteristics for at least 2 years. Accelerated carbonate rock test procedures similar to the Ontario Ministry of Transportation & Communication's "Concrete Prism Test" shall be used to supplement the previously mentioned delayed expansion test; the intent being to replace long term tests with short term tests wherever possible.

3. An immediate intensive field investigation shall be undertaken to determine;
   a) The true extent of alkali-aggregate reactions throughout the State.
   b) The probable aggregate sources involved.

4. To assist field investigators, a "Reaction Identification Kit" shall be assembled consisting of;

a) Numerous colored photographs of typical distress features.
b) Samples of concrete affected by alkali-silica and alkali-carbonate reactions indicating rimmed aggregates and silica gel deposits (if possible). The samples shall consist of 4" cubes cut from specially prepared mortar bars.
c) Colored photos of what and where to look for secondary indicators of probable alkali-aggregate reactions.
d) A classification chart for pavements and structures , based on age, to assist in determining potential severity of distress.

5. Initial determination of individual aggregate source reactivity shall be developed as follows;

a) Both the fine and coarse aggregate sources associated with field designated alkali-aggregate reactivity shall be initially designated potentially reactive and placed on the appropriate "Temporary List of Reactive Aggregate Sources".
b) Immediate steps shall then be undertaken to assign the distress responsibility to appropriate aggregate sources.

Aggregate sources initially determined to be innocuous shall be removed from the temporary reactive list and placed on a "Temporary Non-Reactive Aggregate Source List".

Where either gravel or fine aggregate sources are deemed to be reactive, the entire source shall be placed on the "Temporary List of Reactive Aggregate Sources".

Where rock quarry aggregates are designated "reactive", the entire quarry shall be placed on the temporary list. However, immediate arrangements shall be made to test for the degree of potential reactivity, each and every 6" rock layer of all lithological rock formations represented in the exposed quarry face. (The intent here is to see if selective quarry operations is a practical and economical alternative.)

6. Final designation of the potential reactivity of all fine and coarse aggregates shall be determined on the basis of exhaustive laboratory test results that are compatible with existing field conditions. Where discrepancies occur, field conditions shall always govern.

Eventually all fine and coarse aggregate sources shall be assigned to either the "Permanent List of Reactive (or Non-Reactive) Aggregate Sources".

7. Approval of new fine aggregate and coarse aggregate sources shall be made on the basis of potential reactivity, compatible with results obtained with similar lithologic deposits or formations. If there are any doubts as to the reactive nature of the new aggregate source, it shall be assigned to the "Temporary List of Reactive Aggregates", until such time as exhaustive laboratory test results can be obtained, at which time it shall be assigned to the proper final innocuous or reactive category.

8. A priority list for the laboratory testing of all N.Y. State aggregates, shall be established on the basis of the findings of the statewide field investigations. The highest testing priorities shall be assigned to those aggregate sources found to be associated with the greatest number of seriously distressed structures and pavements.

9. Research should be undertaken to determine the feasibility of treating reactive aggregates with neutralizing chemicals in "scrubber" type units.

10. The general specifications of the NYSDOT shall be immediately amended to require the use of Low-Alkali Cement, defined as containing less than 0.6% sodium equivalent - $Na_2O + 0.658K_2O$, with all designated reactive aggregates. Until more detailed information becomes available, it shall be the ONLY type of cement permitted to be used with all central and western New York aggregates.

11. The use of mineral admixtures to control excessive expansion in concrete due to the alkali-aggregate reaction shall be subject to the test provisions of ASTM C-441.

No admixtures shall be approved for use with reactive aggregates until they are proven to be innocuous.

12. A special note in "bold letters" shall be placed in all appropriate job proposals for at least one full construction year, calling the contractors attention to the importance of conforming to the special low-alkali portland cement requirements. He should be warned that the Department considers this to be an extremely important matter and any failure to comply with the requirements may result in the rejection and removal of the affected concrete units.

13. Low-alkali cements shall be stored in specially approved facillities at the point of manufacture. No shipments shall be made until each individual silo is tested and accepted by the Department.

Subsequent shipment and storage shall be done in a fashion to preclude any significant contamination by high-alkali cements (greater than 0.6% alkalies). The Department shall be the sole judge of what constitutes significant contamination and shall issue guidelines for the benefit of all interested parties.

The initial alkali content of a given cement shall be based upon the average test result of each 10 lb accumulated sample taken for each 1000 bbls of stored cement in each silo. No one individual sample shall exceed 0.6% alkalies.

Additional cement grab samples shall be taken at all concrete batch plants at the cement weigh hopper above the primary mixing unit for every 300 bbls of low-alkali cement used. Cement samples that exceed 0.6% alkalies shall result in the rejection and removal of all concrete placed the date the sample was taken.

Cement alkali content determinations made by the Albany Laboratory on all cement samples, shall be returned to the Region in which the sample was taken. This shall be done for documentation purposes.

The purpose of the multi-sampling procedure is to establish responsibility for specification deviations while aiding in the development of additional control requirements.

14. Any quarry containing both reactive and none reactive aggregates that wishes to follow a selective quarrying procedure, shall submit a written comprehensive report together with appropriate diagrams, sketches a photographs clearly indicating the manner in which the reactive and nonreactive aggregates will be quarried, handled, processed, stored and shipped so that they will in no way become intermingled.

Any nonreactive aggregates contaminated by significant quantities of reactive material shall immediately be considered reactive from that point on in time, and shall be subject to all the appropriate limitations.

The Department shall be the sole judge as to what constitutes a significant contamination and shall issue guidelines for the benefit of all interested parties.

15. All concrete batch plants, either stationary or mobile, located either on or off the contract site, shall be approved once each calender year on the basis of the aggregates and cements to be used.

If only low-alkali cements will be used throughout the approved period, no special restrictions will be placed on the aggregates to be used.

If high-alkali cements are to be used with innocuous aggregates then detailed plans shall be submitted to the Department by the concrete producer at least 45 days before the start of the new calender year, indicating the origin of the aggregates, as well as shipping, handling and storage procedures to be followed. Approval shall not be given unless it can be shown that significant contamination of the innocuous aggregates can not occur.

Any nonreactive aggregates contaminated by significant quantities of reactive material shall immediately be considered reactive from that point on in time, and shall be subject to all the appropriate limitations.

The Department shall be the sole judge as to what constitutes significant contamination and shall issue guidelines for the benefit of all interested parties.

All concrete incorporating high-alkali cements and reactive aggregates shall be rejected and removed from the site.

16. Whenever concrete units exhibiting extensive alkali-aggregate reactivity are being scheduled for repairs, colored photographs of the entire affected unit shall be taken and submitted along with appropriate concrete cores, to the Albany Laboratory for their consideration and comments.

The intent is to avoid repairing severely distressed units that will shortly fail after being repaired. In these cases the entire unit should be removed and replaced.

17. In the central and western areas of the State, immediate consideration should be given, at least on a temporary basis, to the substitution of other construction materials for portland cement concrete wherever possible; i.e. asphaltic concrete pavements for portland cement concrete pavements and steel piers and columns for concrete piers and columns.

18. Manufacturers of all types of pre-cast concrete products shall conform to the same approval requirements applicable to contract concrete producers. All storage and handling facilities and procedures for cements and aggregates shall be approved on a calender year basis. Low-alkali cements shall be sampled and tested for alkali content at least once every two weeks. Any cement sample found to exceed 0.6% alkalies shall result in the immediate rejection of all concrete units produced in that interval of time between the previously approved cement sample and the unacceptable sample.

19. If we are to realize the maximum benefits from the implementation of the proposed aggregate and cement specification changes, it is essential that those engineers charged with the responsibility of enforcing the new requirements understand and believe in them. The necessary mental conditioning of our engineers can best be accomplished through the dessimination of interesting, illustrative, educational information.

Therefore I recommend the Department produce a simple ½ hour to 1 hour long super 8 movie highlighting the reasons why and how alkali-aggregate reactions occur and their ultimate

effect on our portland cement concrete field units. For maximum impact, this movie should be shown in each Region of the NYSDOT in conjunction with the distribution of the new specification requirements. In addition, a simple short booklet, containing appropriate colored photographs illustrating the same important points, should be distributed to all engineers. A knowledgeable Department engineer should be present at all meetings to answer any questions the regional personnel may ask.

It should be made mandatory by the Commissioner, that engineers in all Regions attend these meetings.

Each Regional Materials Engineer should be charged with the responsibility of assembling an "Aggregate Identification Kit" for each aggregate source operating within his area of control. The kits will consist of clear, sealed, heavy duty plastic bags containg selected aggregate samples of the various lithologic material layers indigenous to the approved aggregate source. These kits will be used for comparative purposes by inspectors assigned to contract batch plants operating on and off the contract site.

It is anticipated that the greatest difficulties confronting the implementation of the proposed specification changes will occur at off-site contract batch plants. These plants normally produce concrete for other customers while supplying state contracts. A good portion of this production goes to construction projects belonging to other state agencies and political subdivisions not under the direct control of the NYSDOT. However, they normally require their concrete work to conform to the requirements of the NYSDOT.

The limited cement and aggregate handling, storage, batching and mixing facilities available at these plants, presage the problems likely to occur as both controlled and uncontrolled materials compete for operating room. Therefore, it seems both prudent and wise to make every effort to minimize these potential problems as quickly as possible.

One way to do this is to enlist the aid of as many engineering and concerned manufacturing groups as we can in the launching of our initial efforts aimed at controlling this problem. As a minimum, I would recommend inviting all top engineers and managers from the following groups to the same Regional field engineers meeting proposed earlier;

a) All political subdivisions.
b) All public agencies.
c) All private consulting engineers engaged in State work.
d) All very large private industries.
e) All concrete suppliers.
f) All cement and aggregate suppliers.

By laying all our cards on the table at one time, in front of all concerned parties, in an honest, forthright and determined manner, we will adding considerable emphasis to what we are saying while enhancing the desire to cooperate on the part of all bodies in attendance.

Our employer, the hard pressed, over burdened New York State Taxpayer, will of cause be the chief beneficiary of all financial savings accrued as a result of these suggestions. If we are indeed to be worthy of his hire, we must fulfill our obligation to him and seek to increase the profitability of his truly public corporation. Quality work at minimum cost is the profit he seeks and is entitled to. We, his employees, are both legally and morally obligated to work towards this goal!

Key & Section No.	Slide Number	Slide Date	Year Built & Rebuilt	County	Original & Repair Costs	Aggregate Used	Remarks Bridge No
1	1	1/67	59 to '63	Mon.	?		Eastern Xway and Outer Loop Interchange Complex (12" plus" construction)
	2	4/76	'30 '70	Mon.	$1 mill?		Veteran's Memorial Bridge - Rte 104 & Genesee River 1014830
	3	3/76	'53	Liv.			Mt. Morris Dam
	4	6/76	165 to '69	Mon	11 Mils		Irm. Bay Bridge Rte 104 1052239
	5	11/66		"			" "
	6	11/67		"			" "
	7	4/66		"			" "
	8	11/67		"			" "
	9	7/68		"			" "
	10	7/68		"			" "
	11						
2	12	3/76	'30	Mon			Rte 18 & Sandy CK Excellent concrete 1500± from 1014785 (bridge) 1014760
	13	"		"			" (underside)
	14	3/76	'32	Mon.			Rte 18 & Moorman CK Excellent Conc. 1014770
	15	3/76	'32	Gen.			Rte 33 & Black CK Excellent Conc. with touch A-A 1022990
	16	3/76	'32	Mon			Rte 18 Very few spalls - no blow ups 10 miles of good concrete road with structures
	17	"	"	"			"
	18	"		"			"
	19	3/76	'40	Mon			Rte 215 & YANIZ CK Excellent Conc with only touch A-A 1041320
	20	"		"			" "
	21	11/76	'48	Gen			Rte 262 & Spring CK Excellent Overall Conc. 1043730
	22	"	"	"			" "
	23	3/76	'60	Mon.			Rte 104 & Sandy CK Excellent Concrete 1036440
	24						
3	25	1/71	'40?	Liv.			Rte 5 & Abandoned Penn RR Span 1063850

Section No.	Slide Number	Slide Date	Year Built & Repaired	County	Original & Repair Costs	Aggregate Used	Remarks	Bridge No
3	26	1/71	'40?	LIV.			Rte 5 / Abandoned Penn RR Spur	1063850
	27	11/76	'73	Mon.			Rte 31 (Monroe Ave) / Canal (Wood in deck Case)	4443290
	28	9/64	'64	?			Retarder cracks (too much used)	?
	29	7/64	'64	?			Poor curing procedures	?
	30	9/63	'63	?			Poor deck drainage (design & Construction problem)	?
	31	2/74	'70	Mon.			Rte 104 Ridge Rd / Outer Loop	1062471
	32	3/76	'72	Mon.	? $150,000		Rte 33A / Black Ck "Light Scaling" Sloppy mix	1023080
	33	6/76	'72	GEN.	? $500,000		Rte 5 / Tonawanda CK "Light scaling" Sloppy mix	1001690
	34	11/76	'71	Mon.			Sidewalk "Light Scaling" in front of DOT Bldg Roch.	
	35	"		"			"	
	36	3/76	'17	Monr		Lots of SANDSTONE (No longer used)	Rte 260 / Brockport CK (Severe scaling exacerbated by salts	104360
	37	"		"		"	"	"
	38	"		"		"	"	"
	39	3/76	'66?	ONT (Built) LIV (Stored)		ONON	108" RCP Made in Phelps Stored in Field Geneseo N.Y. (NO SALTS)	
	40	"		"		"	" (close up)	
	41	4/76	'50	LIV.		ONON	ELRR / Rte 63 (NO SALTS)	7028720
	42	3/76	'56 '67	GEN.		ONON	Rte 5 / PCRR (NO SALTS)	1001700
	43	3/76	'56	GEN.		ONON	PCRR / Rte 63 (NO SALTS)	7028770
	44	"		"		"	"	"
	45	"		"		"	"	"
	46	"		"		"	"	"
	47	"		"		"	"	"
	48	"		"		"	"	"
	49	1/76	'22	WYO.		MIXED GRAVEL & CRUSHED STONE	Rte 238 / Stevens Brook (Shaley coarse Agg) (UNSOUND AGGS)	1042450
	50	"	"	"		"	"	"

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
3	51	1/76	'22	WYO.		Mixed Gravel & crushed Stone	Rte 238 ↑ Stevens Brook (Shaley crance Agg) (UNSOUND AGGS) 1042450
	52	"		"		"	" "
	53	4/76	'67	LIV.		?	Rte 390 ↑ Rte 36 (UNSOUND AGGS) 1063761
	54	"		"			" "
	55	3/76	'30	ONT.		GRAVEL	Rte 96 ↑ PCRR spur (GOOD SUBSTRUCTURE - POOR SUPERSTR.) 1034190
	56	"		"		"	" "
	57	"		"		"	" "
	58	"		"		"	" "
	59	5/76	'10	ORLS.		GRAVEL	E195 CANAL BRIDGE (Poor South span) 4445080
	60	"		"		"	(GOOD NORTH SPAN) "
	61	3/76	'54	ORLS.			Rte 237 ↑ E. Branch Sandy Ck Excellent Overall Concrete 1042410
	62	"		"	[illegible] bridge failed		Good deck better than today's "
	63	"		"			(Touch of Determination - A'-A' "
	64						
	65						
	66						
	67						
	68						
	69						
	70						
	71						
	72						
	73						
	74						
	75						

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGNAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
4	1	5/76					Chart - Determination Factors
	2	3/76	'56 '67	GEN		ONON	Rte 5 & PERR (TYPICAL DISTRESS) 1001700
	3						MAP - Aggregate Producing Bedrock Formations In N.Y. State
	4						Quarries & Gravel Pits WESTERN N.Y.
	5		'75		NRMCA PUBLICATION #149		MATHER REPORT '75 Title Sheet
	6				"		" pg 10" - Alkali Silica Criteria
	7				RR 62-7 63-3		INTERIM CHART REPORT Title Sheets & LOCKPORT, MANLIUS, ONON. Report
	8				RR 62-7		Interim Report on Onon Chants Chart Descriptions pg ?
	9				RR 62-7 64-6		Interim & Final Chart Reports Title sheets
	10						McAlpin's 1964 memo to Sweet.
	11				PRP #12 RR 64-6		Bar chart pg 13
	12				"		0.7% Curve pg 15
	13				"		pg 14
	14				"		pg 8
	15						
	16				HRR 124		Bois Blanc Formation So. Western Ontario Canada pg 50
	17				RR 63-3		FRONT OF REPORT
	18				"		14 of 15 most reactive rocks are dolomites & silicons pg 167
	19				"		1/2 x 1" x 2" Rock Core, Test Procedure pg 196
	20						MAP AGGREGATE PRODUCING BEDROCK FORMATIONS IN N.Y. STATE
	21				NRMCA PUBL. #149		CRITERIA ALKALI - CARBONATE REACTION pg 14 BLACK RIVER FORMATION
	22		'64		HRR #45		pg 179 MANTUANI EARLY - LATE MAJOR EXPANDING ROCKS
	23		"		"		pg 183 MANTUANI REVISED EARLY-LATE MAJOR EXPANDING ROCKS
	24		'71		HRR #353		pg 4 & 5 MANTUANI TERNARY PLOT & EXCEPTIONS
	25		"		"		pg 10 & 11 MANTUANI

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REMARKED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
14	26		'64		HRR #45		Ordovician Carbonate Rocks: Virginia pg 223
	27		'71		HRR # 353		Carbonate Rock Distr in U.S
	28		'60		HRB # 275		KINGSTON ROCKS SWANSON & GILLOT pg 20-21
	29				TRR # 525		FORTIFIED ALKALI CEMENT pg 26 & 27
	30		'69		HRR # 268	GRAVEL	CANADIAN SMOOTH GRAVEL pg 100 - 101 MANTUANI
	31		'69		"	"	pg 102 - 103 MANTUANI
	32		'58 '67 '71 '76	ONT	CONST $556,000	GRAVEL	CLOSE UP of Fractured Concrete Rte 96 & Rte 14 1010990
	33		'62		RR 62-14		UNIF. OF CEMENTS
	34				"		"
	35						108" RCP "TYPICAL TAN STAIN"
	36						RECOGNITION CURVE BY AGE
	37						108" RCP "TYPICAL TAN STAIN" 2nd Slide
	38		'63		PCA Public. 1963		GEORGIA, ALABAMA BRIDGES 1963 "TAN STAINS"
	39						C.A. Carpenter Letter to M. Graham 12/3/63
	40		'58 '67 '71 '76	ONT		GRAVEL	CLOSE UP OF FRACTURED CONCRETE Rte 96 & Rte 14 1010990
	41				NRMCA '75		RIMMED AGGS & GEL pg 4 BRYANT MATTHER
	42				RR 64-6		FINAL CHERT REPORT pg 3 "CAN'T FIND GELS" LAB MORTAR BARS.
	43	3/76	'60	MON		LOCKPORT	Rte 490I WB & Ramp C PAV'T EXP. 1052260
	44	3/76	'60	"		"	" " "
	45	3/76	'60	"		"	" " "
	46	3/76	'60	"		"	" " "
	47	4/76	'60	MON		LOCKPORT	Rte 441C (Pennfield RD) & 490I PAV'T EXP. 1048510
	48	3/76	'60	"		"	" " "
	49	3/76	'60	"		"	" " "
	50	3/76	'62 '63	MON		LOCKPORT	Rte 490I. & EAST AVE PAV'T EXP. 1026010

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
14	51	3/76	'62 CO '63	MON		LOCKPORT	490I to East Ave PAV'T. EXP. 1026010
	52	7/76	'54 '68	MUN		LOCKPORT	Rte 31 to 490I (PAVEMENT OUT?) SEWN PAV'T EXP. 1021690
	53	7/76	"	"		"	" "
	54	7/76	"	"		"	" "
	55	7/76	"	"		"	" "
	56	7/76	'54 '68	MON.		LOCKPORT	Rte 490I to 31F (PITTSFORD) (PAVT EXP) 1022119
	57	7/76	'54	MON		"	SEPARATION RAMP PAV'T & MALL Rte 31 to 490I (PAVT EXP)
	58	3/76	66?	ONT LIV		ONON	108" RCP (EXPANSION) in Field @ Genesee 10 yrs old
	59	"		"		"	CLOSE UP 108" PIPE
	60	"		"		"	PIPE STRESS ANALYSIS
	61	"		"		"	pipe interior
	62	"		"		"	close up pipe interior
	63						"MPR" Concrete Test Cylinder
	64	12/76	'62	MON		LOCKPORT	Col. SHEAR FAILURE Rte 47 NB Ramp to 490I WB 1052290
	65	"		"		"	" "
	66	"		"		"	" "
	67	"		"		"	" "
	68						108" RCP
	69						"MPR" - REINF CONC BRIDGE DECK
	70	1/77	'63	MON		LOCKPORT	ELMWOOD OVR to 47 (No salt spalls? Lit. Str. tension cracks 1025970
	71	"		"		"	" (limited spalls?) "
	72	"		"		"	" "
	73	1/74	'70	MON.		LOCKPORT	(Ridge RS) Rte 104 to Rte 47 (MANY SPALLS) 1062471
	74						
	75						

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
15	1		5/63		RR-63-4 PR #24		PR #24 ROCH BRIDGE REPORT
	2	'69	'54 '59 '71	MON	$2,480,000 312,000 6,300,000	LOCKPORT	TROUP HOWELL BRIDGE (So. Face) 1050129
	3	10/76	'54	MON		LOCKPORT	B&O RR ↑ Mt Read 7049760
	4		5/63		RR 63-4 PR #24	LOCKPORT	May '63 Mentions Rimmed Aggs pg 16
	5				"	LOCKPORT	pg 19
	6	7/76	'54	MON		LOCKPORT	B&O RR ↑ Mt Read (TAN STAINS) 7049760
	7		5/63		RR 63-4 PR #24	LOCKPORT	pg 13
	8						FOUR RESEARCH REPORTS
	9				RR 65-9		Mal Graham's Transmittal letter
	10						McLean's Memo Jan 21, 1971
	11				RR #11		Abstract "Techniques For Measuring Air Void Characteristics of Concrete"
	12						CONCRETE ALL AGES REGION #4
16	13	12/76	'07	ONT		GRAVEL	RR ↑ Rte 20 Canandaigua 7001880
	14	"	"	"		"	" "
	15	"	"	"		"	" "
	16	2/71	'10	MON		GRAVEL	E144 Canal Bridge CLINTON AVE 4043100
	17	4/76	'10	GEN		GRAVEL	RR ↑ County Rd (None State Bridge)
	18	4/76	'25	WYO		ONON	Rte 20A ↑ Tonawanda CK 1016130
	19	4/76	'31	LIV.		GRAVEL	Rte 39 ↑ Unknown CK 1024620
	20	"	"	"		"	" "
	21	"	"	"		"	" (Note unsound aggs [illegible]) "
	22	"	"	"		"	" "
	23	3/76	'31	Mon		Onon (Deck) Gravel (Substr.)	Rte 18 ↑ Sandy CK 1014770
	24	"	"	"		"	" "
	25	3/76	'31	ORLS	? $500,000? [illegible]	Onon (Deck) & Gravel (Substr.)	Rte 31 ↑ PCRR ABANDONED 9021560

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS	BRIDGE No
16	26	3/76	'31	Orls	? $500,000 min	Onon (Deck) Gravel (Subst)	Rte 31 / PCRR [illegible]	9021560
	27	"		"		"	"	"
	28	"		"		"	"	"
	29	"		"		"	"	"
	30	5/76	'37	MON.		GRAVEL	Rte 383 / PCRR	1047220
	31	"		"		"	"	"
	32	"		"		"	"	"
	33	4/76	'38	Mon		ONON.	Rte 65 / LURR	1028960
	34	"	"	"		"	"	"
	35	"	"	"		"	"	"
	36	"	"	"		"	"	"
	37	"	"	"		"	"	"
	38	3/76	'40	MON		Lockport ?	PCRR / Rt 33A	7023120
	39	"		"		"	"	"
	40	"		"		"	"	"
	41	4/76	'41	LIV.		GRAVEL	Rte 36 / ELRR	1023680
	42	"		"		"	"	"
	43	"		"		"	"	"
	44	"		"		"	"	"
	45	3/76	'41?	LIV		GRAVEL	Rte 5 / Avon PCRR Spur (AVON)	1063850
	46	"		"		"		"
	47	"		"		"		"
	48	"		"		"		"
	49	"		"		"		"
	50	"		"		"		"

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
1/6	51	3/76	'41?	LIV.		GRAVEL	Rte 5 ↑ Abam PCRR Spur (AVON) 1063850
	52	"		"		"	" "
	53	"		"		"	" "
	54	4/76	'44 '49	WYO.	?	Gravel ?	Rte 362 ↑ Wiscoy CK 1046610
	55	"	"	"		"	" "
	56	"		"		"	" "
	57	7/76	'48	ONT.		ONON.	Rte 332 ↑ LVRR 1046050
	58	"		"		"	" "
	59	"		"		"	" "
	60	7/76	'52 '61	GEN		ONON.	Rte 33 ↑ Tonawanda CK 1022969
	61	"		"		"	" "
	62	"		"		"	" "
	63	7/76	'53	ONT.		ONON ?	NYS TRWY ↑ Rte 96 1035179
	64	7/76	'54	ONT.		ONON.	THWY ↑ FISHER RD. (TRWY struct.) ?
	65	"		"		"	" "
	66	7/76	'54	MON.	RR63-4.	LOCKPORT	BEORR ↑ MT READ SWWW 7049760
	67	"		"		"	" "
	68	"		"		"	" "
	69	"		"		"	" "
	70	3/76	'56 '67	GEN.		ONON.	Rte 5 ↑ PCRR 1001700
	71	"		"		"	" "
	72	"		"		"	" "
	73	"		"		"	" "
	74	4/76	'58	ONT		GRAVEL	Ped Br ↑ Rte 5 & 20 1001740
	75	"		"		"	" "
	76	"		"		"	" "

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REMARKED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
1	1	3/76	'60	MON		LOCKPORT	49 & 490I & RAMP C CAN OF WORMS 1026020 1052260
6	2	"	"	"		"	" "
	3	7/76	'60	MON		LOCKPORT	47 & 490I 1026020
	4	3/76	'60	"		"	490I NB " & RAMP C 1052260
	5	6/76	'60	MON		LOCKPORT	441 & 490I 1048519
	6	"	"	"		"	" "
	7	"	"	"		"	" (PIER FAILURE) "
	8	4/76	'61 '62	MON		LOCKPORT	RTE 490I WB & CANAL 4443361
	9	"	"	"		"	" "
	10	"	"	"		"	" "
	11	7/76	'61 '62	MON.		LOCKPORT	RTE 47 NB & 490I WB (PIER MOVED) 1052290
	12	"		"		"	" "
	13	"		"		"	" (COL FRACTURE.) "
	14	"		"		"	" (COL FRACTURE) "
	15	10/76	'62	MON		LOCKPORT	RTE 47 & 286A BOSSOM RD 1026041
	16	"		"		"	" "
	17	"		"		"	" "
	18	"		"		"	" "
	19	3/76	'62	MON		LOCKPORT	RT 47 & 286 BROWNCROFT BLVD 1026050
	20	"		"		"	" "
	21	10/76	'65	ONT		GRAVEL	RTE 20A & MUD CK 1016230
	22	10/76	'65	GEN.		ONON.	ELRR & RTE 98 7035710
	23	"		"		"	" "
	24	"		"		"	" "
	25	"		"		"	" " (CULVERT / WALL)

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
6	26	3/76	'66	LIV.		?	Rte 390I SB ↓ Rte 36 1063760
	27	"	'66	"		?	" "
	28	4/76	est ? '68	MON		LOCKPORT	Rte 104 (Ridge Rd) ↓ IRON. BAY 1052239
	29	"	"	"		"	" "
	30	"		"		"	" "
	31	"		"		"	" "
	32	3/76	'68	MON		LOCKPORT	47NB ↓ Rte 31 (fine agg A-A.) Bates & Rogers 1021660
	33	5/76	'70	MON		LOCKPORT	Rte 590I ↓ Latona Rd 1062491
	[illegible]	"		"		"	" "
	35	5/76	'70	MON		LOCKPORT	Rte 590I ↓ WEILAND Ave 1062502
	36	7/76	'72	MON		LOCKPORT	Rte 414 ↓ NO PCRR 1063919
	37	4/76	'72	MON		LOCKPORT	TROUP ST ↓ GENESEE RIVER "
	38	4/76	'72	MON		LOCKPORT	Str #11 CLINTON AVE BRIDGE ?
	39	4/76	'72	MON		LOCKPORT	Prestress Str 11 ?
	40	4/76	'72	MON		LOCKPORT	Prestress PLYMOUTH AVE ↓ 490I ?
	41	4/76	'72	MON	all show tow stain	"	" crack and stain ?
	42						
7	43						CHART - A-A Bridges Region #4
	44				Determined		STRUCTURES ALBANY TO BUFFALO
3/8	45	11/76		NIA		LOCKPORT ?	Rte 190 ↓ Rte 37 (Note separation of good [illegible] concrete)
	46	11/76		"		"	" "
	47	4/76		ERIE			Rte 277 ↓ THWY CONN. Buffalo
	48	8/76	'40	ERIE			Balance Conc Excellent Rt 5 & 20 Slight A-A 7013340
	49	[illegible]	?	ERIE	SAMPLED		? Buffalo Classey Deposits? (Slag)
	[illegible]	4/76	'54	ERIE	SAMPLED		Buffalo, N.Y Just South of Toll Booth Sample Conc [illegible]

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
8	51	7/76		GEN	SAMPLED		THWY & Rte 5 10016[illegible]
	52	3/76		STEU			Rte 21 & 36 & Channel Hornell
	53	3/76	'58?	"			" " Hornell
	54	5/76		STEU.			Rte 415 & Cohuston River.
	55	5/76		STEU			Rte 17 & Rte 415 North of Bath
	56	5/76		STEU			"
	57	3/76		STEU		GRAVEL	Rte 36 @ Bowen Rd E Seneca Hornell
	58	5/76	'67?	CHEM			Rte 17 Horseheads
	59	5/76		"			"
	60	4/76	'60	SENECA		GRAVEL	Rte 96A & 5 & 20 waterloo
	61	4/76		"		"	"
	62	4/76		"		"	"
	63	10/76		SENECA		GRAVEL	RR & Rte 5 & 20
	64	"		"		"	"
	65	"		"		"	" (No salt)
	66	10/76	'70?	WAYNE		LOCKPORT?	Rte 350 & Canal
	67	"		"		"	"
	68	8/76	'54	ONON		ONON	Rte 690 & RR
	69	"	"	"		"	"
	70	"	"	"		"	"
	71	8/76	'60's	CAYU		ONON?	RR & THWY Just east of Weedsport per Georgia (Mottled effect)
	72	"		"		"	THWY Exit 40 (Mottled effect)
	73	"		"			(Mottled Effect

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No [illegible]
/8	1	8/76	? '40's	CAYU		? SNDN	Rte 31 & 38 of CK Port Byron
	2	8/76	? '30's	CAYU	SAMPLED	? SNDN	Rte 34 of PCRR North of [illegible]
	3	"		"		?	"
	4	"		"		?	"
	5	"		"		?	"
	6	[illegible]	'54	CAY		?	ABUT, PIERS, DECK, - Repaired or Replaced Rte 34 of THWY North of [illegible]
	7	6/76	?	?		?	Between FULTONVILLE & UTICA
	8	6/76	?	?		?	FULTONVILLE
	9	10/76		SCHEN		GRAVEL	Rte 9A of Rte 7 1/4 Mile above Exit 25
	10	"		"		"	"
	11	10/76		ALBANY		?	Rte 490I of Central Ave
	12	"		"		?	"
	13	"		"		?	"
	14	6/76		ALBANY		?	STATE CAMPUS Washington Ave of Outer Loop opposite Bldg #2 & #5
	15	"		"		?	"
	16	"		"		?	"
	17	"		"		?	"
	18	"		"		?	"
	19						Old Quarry MAP NY STATE
	20				Repaired	structures	
5/9	21	2/62	'54	Mon		LOCKPORT	Ridge Rd of Mt Bend 1036469
	22	"		"		"	" "
	23	5/64	'54	Mon.		"	" "
	24	"		"		"	" "
	25	5/64		"		"	" "

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No Cont'd Repaired Structure
19	26	4/76	'54 '63	MON	$125,000 $224,960	Lockport	Ridge Rd (Rte 104) & Mt Read 1036469
	27	4/76	"	"		"	"
	28	4/76		"		"	" "
	29						
	30	1/62	'54 '59	MON	2,480,000 312,000 6,300,000	Lockport	Trout [illegible] & [illegible] 1050129
	31	10/59		"		"	"
	32	10/59		"		"	"
	33	10/59		"		"	"
	34						
	35	1964	'54 '65	MON		Lockport	Mt Read & NYCRR 1049759
	36	4/76		"		"	" "
	37						
	38	5/76	'54 '68	ONT	320,000 650,000 (330,000 over run)	GRAVEL	Rte 5 & 20 & PCRR 1001939
	39	5/76	"	"	"	"	" "
	40	4/76	"	"	"	"	Rte 14 & 5 & 20 "Conc continues to deteriorate" 1001920
	41	4/76	"	"	"	"	" "
	42						
	43	4/76	'54 '60? 76 repaired	MON.	? ? $333,000	?	Rte 36 & THWY 1023760
	44	4/76		"		?	" "
	45	4/76		"		?	" "
	46				☆ CLASSIC EXAMPLE		Investigated by Department Found No A-A evidence.
	47	1/71	'58 '67 '71 '76 repaired	ONT	? ? ? $556,000	GRAVEL	Rte 96 & Rte 14 1010990
	48	1/71		"		"	" "
	49	1/71		"		"	" "
	50	1/71		"		"	" "

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
1	51	1/71	158 167 171 176	ONT	? ? ? $56,000	GRAVEL	Rte 96 to Rte 14 1010990
	52	"		"		"	" "
	53	3/71		"		"	" "
	54	"		"		"	" "
	55	6/71		"	Nine [illegible]	"	" "
	56	"		"	[illegible] for one time	"	" "
	57	"		"		"	" "
	58	"		"		"	" "
	59	3/76	[illegible]	"	[illegible]	"	" "
	60	"		"		"	" "
	61	"		"		"	" "
	62	"		"		"	" "
	63	"		"		"	" "
	64	"		"		"	" "
	65	"		"		"	" "
	66			"		"	" "
	67	"		"		"	" "
	68	"		"		"	" "
	69	3/76		"		"	" "
	70	12/76		"		"	Final Result - Start all over again

SECTION No.	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGINAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No Problems other than [illegible]
/10	1	12/76		MON		ONON?	Private Light Pole Base Scottsville
	2	4/76	'31? '73	MON.	$3,400,000	GRAVEL? LOCKPORT	Broad St Tunnell and Viaduct
	3	1/77		"		"	Crack and Pratuch Effect
	4	1/77	'73?	"		"	" "
	5	10/76	'73	MON.	Better than $1,[illegible]	?	Manhattan Sq Park Rochester, N.Y.
	6	10/76	"		"		" Crack & Stain
	7	1/77	?	MON	?	?	Highland Hospital - Note reinforced [illegible] Retaining wall
	8	"					Fractured at end
	9	"					Mottled effect (same on some Georgia Bridges?)
	10	"					Cracks & stains in Bldgs
	11	7/76	'59 '?	ORLS	Repaired once [illegible]	?	3 Mill gal Town Water Reservoir Medina along Rt 31A
	12	"		"	"		" Tan stain
	13	11/76		NIA.		Lockport?	POWER AUTHORITY
	14	"		"			"
	15	"		"			"
	16	"		"	Spalls [illegible]		"
	17	"		"			"
	18				RUSTING OF STEEL		
/11	19	12/76	'14	ORLS		GRAVEL	E 209 Medina New York No deterioration around Scuppers note exposed rebars.
	20	"	"	"		"	"
	21	7/76	'14	ORLS		GRAVEL	E 210 to Canal Medina Eagle St Note slight deck scaling - some patterns
	22	"	"	"		"	Note exposed rebars little spalling
	23	11/76	'48	GEN.		ONON.	salt laden dirt lays on curb - [illegible] Rte 262 only [illegible] 104372[illegible]
	24	11/76	"	"		"	rebars @ surface - only little spalling "
	25	11/76	"	"		"	" " "

SECTION	SLIDE NUMBER	SLIDE DATE	YEAR BUILT & REPAIRED	COUNTY	ORIGNAL & REPAIR COSTS	AGGREGATE USED	REMARKS BRIDGE No
1/11	26	11/76	'48	GEN		ONON.	Rte 262 & Oak Orchard Ck Holes @ surface 1043720
	27	11/76		"		"	" "
	28	11/76		"		"	" "
	29						
1/2	30						Model of proposed #20 Mill plus bridge & viaduct across Gen. River Rock
	31						
	32						
	33						

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LRI